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PROCEEDINGS OF CONFERENCE

ON

INSULATION

for

electrically heated and cooled houses

Agricultural Research Service

UNITED STATES DEPARTMENT OF AGRICULTURE

PREFACE

The Conference on Insulation for Electrically Heated and Cooled Houses developed from discussions and suggestions of members of the American Society of Agricultural Engineers Electric Utilization Research Committee. This Conference was sponsored jointly by the American Society of Agricultural Engineers and Agricultural Research Service, USDA, and held at the National Housing Center, Washington, D.C., June 1-2, 1961. These members recognized that designers, manufacturers, installers, power suppliers, and others in the field were encountering technical problems and questions for which they did not have ready solutions and answers. It was concluded that many of the needed solutions and answers could be made available if the technically well informed specialists in the problem areas could be brought together for an exchange of information. As a result the Agricultural Research Service of the U.S. Department of Agriculture was requested to Co-sponsor and arrange this Conference.

The purpose of the Conference is stated as: "To develop and disseminate the most current information on technical and economic factors affecting the design and installation of insulation in electrically heated and/or cooled houses", certainly the discussions in the papers presented at the Conference developed this information. We trust the proceedings will disseminate it where needed.

Special credit is due Mr. L. J. Endahl, Secretary of the Committee and Agricultural Engineer, National Rural Electric Co-operatives Association, for his efforts in apprising the Agricultural Research Service of the need for the Conference and for his suggestions on the program coverage.

Special credit is also due Mr. M. C. Ahrens, Assistant Chief, Farm Electrification Research Branch, and Mr. J. W. Rockey, Assistant Chief, Livestock Engineering and Farm Structures Research Branch, both of the Agricultural Engineering Research Division, Agricultural Research Service, for planning and arranging the Conference.

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ELECTRIC UTILIZATION RESEARCH COMMITTEE
AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

WHAT MAKES ELECTRIC HOUSE HEATING PRACTICAL?

by

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The theme of this conference, insulation, heads the list of what makes electric home heating practical. Improved materials and techniques of insulation and a growing awareness of its benefits have been the sparks that set off the explosive growth of electric heating in the past few years. These, coupled with increasing fuel costs while electricity has mainly held firm on rates, have made possible effective, practical and economical application of electricity for home heating. Growth was experienced because of two basic concepts:

1. Savings in first cost of the heating system, and parts of the building dictated by the heating system were applied to better thermal construction of the building. Thus the better insulated, electrically heated building was competitive in first cost with the conventionally built, conventionally heated building.

2. Having accomplished the first, the electric heating system was competitive in total annual owning and operating costs, when all costs were considered. But let us look at these ideas in more detail.

Heating System Costs: An electric heating system, installed, is normally less expensive than a comparable combustion system. This does not mean that any electric heating system is lower in cost than any combustion system; that baseboard electric heat is less costly than a minimal type of combustion system utilizing forced warm air. It does mean, however, that a baseboard electric heating system is substantially less costly than a baseboard hot water system; that ceiling cable can be installed at less cost than a minimal type of forced warm air system using combustible fuel. In addition, to be comparable, the combustion heating system should have approximately the same flexibility of control as electric heat. Provision of effective room-by-room controls to combustion heating systems is normally impractical.

Parts of the building are not normally considered a cost of the heating system, since they are not included in the heating contract. However, those parts whose only purpose is to permit the combustion heating system to be installed and operated are as true a part of the cost of the heating system as if they were in the heating contract. The space for the furnace or broiler, the stack or chimney, the gas meter and service or oil storage facilities, are each a definite cost incurred for no purpose other than accommodation of the heating system. If the heating system limits furniture placement within the heated space (and most combustion heating systems do) the value of the heated space is reduced by some amount dependent on the limitations.

Good practice dictates insulation of the building to insure a reasonable heat loss (the desirable level being presently under close scrutiny). Savings in heating system, and parts of the building dictated by the heating system, provide substantial funds available for insulation. These may be greater, or exactly equal or may be slightly less than necessary to do a proper insulating job. Regardless of which of these patterns fits, the better insulated electrically heated building is provided at a cost competitive with conventional construction.

Insulation: Insulating practices appear to have been neglected for many years before widespread use of electricity for heating. With costs of building buildings tending upwards, with fuel costs rising rapidly, with heating equipment costs up, and installation costs up, higher levels of insulation would appear to have been in order; yet insulating practice showed little or no change. In the meantime, new techniques and new materials of insulation as well as a greater volume of materials used and the greater competition among insulation suppliers, all combined to lower the cost of better thermal construction. Yet, in 1955 conventional heating and air conditioning practice was to use a maximum of 4 inches of insulation in the ceiling, 0 to 1 1/2 inches in the side-walls and nothing in the floors.

When electric heating began to be more widespread in use (about 1958) 6" ceiling insulation was considered impractical by most people. It is commonplace, and economically available, today. Floor and perimeter slab insulation were rare 6 years ago. They are commonplace today. Insulation levels of 10" and 12" in ceilings, 6" in walls and 8", 10" and 12" in floors are being demonstrated by both theory and practice to be more economical in total annual owning and operating cost than lesser amounts in areas with unusual weather and energy costs. These higher levels will be acknowledged more economical than lower levels everywhere in the country, with a wider realization that insulation returns greater dividends in capacity and energy saved per year than present theory credits it. It is my opinion this realization will be reached in another year or so.

But we must not discuss insulation so glibly and generally. We must depart from "thickness" as a criterion, and think more in terms of effectiveness of thermal resistance. We must evaluate this thermal resistance in relation to cost -- lest we recommend a thermal construction which becomes economically unsound in certain building constructions. A kilowatthour or Btu saved in the ceiling is just as important as one in the sidewalls -- regardless of how many or how few were saved by preceding insulation, (excepting significant comfort influences of location, like floors, where a few degrees will affect comfort so materially, or very poor walls and single glass, where the low mean radiant temperature might affect comfort). No such thing as "more insulation than is practical" can exist if the net cost of the insulation (what it costs to put it there minus the cost of heating and cooling equipment rendered unnecessary by it) is equalled by operating cost savings (of heating and cooling) in a reasonable time.

This should be our criterion -- to recommend insulation levels that result in the lowest combination of mortgage payments plus operating costs. With this evaluation, the operating costs savings are pure gain after the mortgage is paid off.

Relative Humidity: Another important aspect of home heating is control of relative humidity. In the better insulated and weatherstripped house the moisture added to the air by normal living (cooking, bathing, breathing, and perspiration) is usually more than enough to overcome the drying effect of air infiltrating from outside, and to maintain a higher than desirable relative humidity in the house. Consequently, it is always recommended that for a good electric heating installation an exhaust fan be provided at the cooking range and in the bathroom. Either, or both, are frequently recommended to be controlled by a humidistat as well as being available for manual operation. The humidistat is normally set, or manual operation used to limit the inside relative humidity to approximately 40%. This is a very pleasant relative humidity, and with the double glazed windows which are present with any good electric heating installation, condensation of moisture on the windows is prevented.

There are two schools of thought on the desirability of a vapor barrier in walls and ceiling especially, to prevent moisture which might pass through from the inside to the building section from condensing within the building section to give structural and decoration problems as well as possibly reducing the effectiveness of the insulation in use. We shall look forward to the comments of our speakers today on this subject, but either school of thought agrees that it is essential to insure that the barrier to vapor flow from the building section to the outside is significantly poorer than the barrier to vapor flow from the occupied space to the building section. One school of thought recommends careful application of an adequate vapor barrier on the inside to accomplish this result, while the other recommends that whatever vapor barrier exists on the inside (having selected interior finish materials for reasons other than the vapor barrier), the barrier to vapor flow on the outside be made poorer by punching small holes in it if necessary. At the present stage of the art, my personal preference is to gratefully accept the best inside vapor barrier available at little or no added cost. However, I do not feel justified in paying anything significant for an improved vapor barrier on the inside. Having established the vapor barrier level on the inside, I will insure that the outside barrier is significantly poorer even if this means deliberately destroying the vapor barrier automatically provided on the outside construction materials.

Ethical Selling: It is only natural for manufacturers, distributors and contractors to emphasize the advantages and features of the particular brand of equipment they represent. It retards the acceptance of electric heat (and by retaliation their own progress), if in the process they raise doubts concerning the desirability of methods of application of electric heat which they might not favor for personal or commercial reasons. One of the strengths of electric heating is the variety of methods of application available, each with advantages and disadvantages compared to others. There are valid reasons for preferring baseboard heaters, unit heaters, infrared radiation, wall insert heaters, central furnaces, duct heaters in branch air runs, ceiling cable or floor furnaces for specific uses. We should each exert our influence, by example, and by unrestrained displeasure at violations, to insure that in the enthusiasm of "selling" one particular heating method, some other methods of heating with electricity are not represented to prospective users as utterly impractical and undesirable.

Positive selling, and realistic discussion of advantages and comparative disadvantages of various ways of doing the job electrically are healthy. Negative selling, "knocking", or false and exaggerated stressing of less desirable characteristics of other means of electric heating are against the best interests of the industry -- and we should fight to stamp them out!

Points Requiring Clarification: There are a number of details concerning the application of electric heating to homes which require some clarification. On most of these there are various schools of thought, and we sorely need factual information based on field experience to determine what approach correlates best with actual experience. A quick look at some of these problems:

1. Infiltration. The NEMA Manual presently recommends the use of one air change per hour in calculating the load due to infiltration of outside air. The ASHRAE Guide recommends one to two air changes for residential, but with a footnote that permits reduction to a minimum of one-half air change for weatherstripped homes. The difference between figuring on half an air change and a full air change is quite significant, and the better insulated the building the more important this question becomes. Under the old established 6-4-2 insulation standards, one air change per hour represents nearly 40% of the calculated heat loss. If this figure is twice as high as it should be, we are radically overestimating this portion of the load. Under the heavier levels of insulation being seriously considered today, the error is even more significant.

   There is adequate reason to believe that any residence reasonably well built and not over 2 stories in height (which accommodates most tri-level houses) will experience a maximum average infiltration for the season of one-half air change per hour. If this is the case, we urgently need to get this information into the hands of the industry, and revise our calculating procedures accordingly.

   We look forward to some definitive information on this score in our meeting today.

2. Basements. Authoritative data on the heat losses of basements is hard to find. This is probably because houses heated with combustion systems have almost universally found the basement comfortably heated by vagrant heat from the heating system installed in the basement. When we remove the heating system and breeching to the stack, we have left the basement without any source of byproduct heat. Unless electric heat is applied, we leave the basement uncomfortably cold. No matter how little one might plan to use the basement, I consider it a mistake to leave the basement uncomfortable. If we leave the basement unheated, good practice dictates insulating between the basement and the occupied space above. This involves a greater area to be insulated than if we insulated all of the basement outside walls adequately. The basement

with insulated walls should be maintained at a minimum temperature of about 55° to insure comfort on the floor above. It is my opinion that an insulated basement maintained at 55° will use insignificantly more energy for heating than a house with an unheated basement and insulation between the occupied space and the basement. Confirmation (or refutation) is again sorely needed.

One of the pitfalls of basement insulation is the home owner's tendency to desire attractive wall treatment over the insulation, such as high quality finished plywood. The cost of such treatment should not be charged to the insulation. There would seem to be two very practical means of insulating the basement. One would be to fur out and install the insulation that would otherwise be used between the basement and the occupied floor, covering this insulation with dry wall. For a basement with assurance of no leakage of water whatever, the use of foil faced plasterboard (with the foil facing toward the basement wall) as the only insulation gives a quite inexpensive and reasonably satisfactory insulating job. We can hope an effective, inexpensive, easily applied spray on plastic insulation might soon appear, suitable for use without the expense of further surface treatment for appearance or ruggedness.

3. <u>Multiple glazing</u>. Double glazing with Thermopane or Twindow is presently reasonably well received in most climates. Along with the better thermal construction of the walls and ceilings being considered today, there is every reason to consider seriously triple glazing (Twindow or Thermopane in the sash, with storm windows added) for most areas, and most certainly for areas where the outside temperature is below -15°F. or degree days are above 7000 per year. The actual cost of double and triple glazing is not near as much as it is customarily evaluated, and use of multiple glazing is, in my opinion, economically sound anywhere in the country.

4. <u>Calculations of loads and energy use</u>. Conventional methods of calculation (NEMA Manual and ASHRAE Guide) each result in calculated heat losses and estimates of energy consumption which are considerably greater than actually experienced with electric heat in homes. Where records are kept of the electrical demands experienced, it is normally found that the maximum demand experienced is something less than 3/4 of the calculated heat loss of the building. This figure indicates 33 1/3% more capacity being installed than is necessary. A more realistic sizing of equipment would result in lower installation costs, and actually greater comfort during the heating season, since oversized heating systems are less comfortable to live with than systems realistically sized.

The NEMA Manual recommends use of a "C" factor of 18-1/2. Theoretically, this figure should be 24, yet actual experience is indicating good correlation using "C" factors of 16 or 17 in homes insulated to the 6-4-2 level. In many extremely well insulated homes "C" factors of 12 have been recorded.

These thoughts lead to the interesting conclusion that insulation and multiple glazing (which is really insulation of transparent glass areas) return greater dividends in capacity saved and energy consumption saved than conventional calculations indicate they will. This, combined with the tendency to overestimate the actual cost of better thermal construction, leads to a completely unrealistic evaluation of the economics of better construction. It is my belief that much higher levels of insulation than are currently being recommended generally will be found to be desirable and economical when we are all provided with better means for realistic evaluation of the costs and benefits of better thermal construction.

The growth of electric home heating in the past few years has been truly phenomonal. Meetings of this type, leading to a better understanding of proper application of electric heat can only result in better jobs, more satisfied users, and still more rapid growth. We can all take a great deal of satisfaction that with this tremendous growth in electric home heating there are relatively few inadequate or unsatisfactory jobs. And yet, we are concerned that there are <u>any</u> inadequate or unsatisfactory jobs. Is there anything we can do to improve our "batting average"?

It is my opinion that an experienced observer can visit any unsatisfactory or inadequate electrically heated home during the heating season, and determine, without too much difficulty, which of the principles of practical application of electricity to home heating have been violated. If the outside temperature is 20° or colder (or the actual temperature difference is at least half the design temperature difference in milder climates) inadequate insulation, or places where insulation has been omitted, can be detected by checking of inside surface temperatures, often adequately by hand sensation alone. The causes for condensation on the inside of windows, on the inside of outer panes of storm windows, or within the building sections themselves, can be determined by an experienced observer. When the individual trade worker becomes aware that deficiencies in his work can be determined without tearing the building apart, our problems of securing high quality workmanship will be primarily those of adequate communication to let the craftsman know what is required. Therefore, in my opinion, the constructive measures we can take to maintain and even improve the significant record of satisfaction with electric heat can be summed up in the two words <u>education</u> and <u>communication</u>.

We need to educate ourselves, and then, all of our trade allies in the construction and electrical field as to what constitutes the proper building and the proper installation of electric heat within the building to secure maximum satisfaction and comfort. We need to communicate this information to them, along with the further information that an experienced observer can readily detect any violation of these principles should they occur.

For the balance of today, and a significant part of tomorrow, we will be afforded an opportunity to educate ourselves on some of the phases involved in consideration of the building and its electric heating system. If you are looking forward to this opportunity with the same enthusiasm I am, our speakers who are to follow will receive undivided attention, and I am sure that each of us, and the electric industry, will benefit by these sessions.

INSULATION - PAST AND PRESENT

by

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A week ago we had the privilege of driving through part of the Department of Agriculture's establishment at Beltsville, Maryland. Passing through the fields and by the various buildings which, together, remind you of a gigantic college campus, we were struck by the paradox of how tranquil it seemed and how effective the Department has been.

Certainly the most basic and important human endeavor is agriculture. And it seems to me it's all too often overlooked that in this most important endeavor the United States is unquestionably generations ahead of the rest of the world. Though the Soviet Union spends <u>twice as much</u> as we do on agriculture, they are not yet <u>half</u> so far along the way. That the Department, one hundred years old next May, has had a tremendous influence on this record cannot be questioned.

Perhaps one of the reasons for the Department's success is that it is interested not only in things that grow but in the people who grow them. These interests are...and have always been...long-range interests. As a result, I don't think it strikes anyone as being strange that we are here as guests of the Department of Agriculture to discuss electric house heating. Nor is any of us surprised that the rural co-ops are as advanced as any other group developing and promoting electric house heating. These groups, along with the private utilities, public power, and municipal systems, are working just past the threshold of an idea that will unquestionably, in a relatively short time, create the need for incredible amounts of electric energy to both heat and cool homes.

The extraordinary acceptance of electric heating in these, its very early days, should not blind us to the actual fact that it is in fact both quite new and quite unique. And equally unusual is the concern of electric heating proponents that the energy involved in their system be conserved and controlled through the use of adequate insulation. Undoubtedly this concern has had much to do with its early success. For it is true that until electric heating came along, never had any industry been concerned about conservation of the fuel it supplied. This was so, despite the fact that the principles of insulation were well known and insulation materials were available back in the days of the fireplace.

That there is cause to be concerned about energy resources, and that the electric heating and cooling advocates are correct in insisting on built-in conservation and control in their systems, has been well established. But I

have never seen the cause so well described as in a recent book by Admiral Rickover. What this distinguished atomic pioneer has to say, in part, about the past and present use of energy is well worth the time it takes to consider. Said the Admiral:

"We live in what historians may some day call the Fossil Fuel Age. Today coal, oil, and natural gas (including their use to generate electricity) supply 93 per cent of the world's energy; water power accounts for only 1 per cent; and the labor of men and domestic animals the remaining 6 per cent. This is a startling reversal of corresponding figures for 1850, little more than a century ago (and just 12 years before the founding of the Department of Agriculture). Then, fossil fuels supplied 5 per cent of the world's energy, and men and animals 94%. Five-sixths, or 83%, of all the coal, oil, and gas consumed since the beginning of the Fossil Fuel Age has been burned up in the last fifty-five years.

"These fuels have been known to man for more than three thousand years. In parts of China, coal was used for domestic heating and cooking, and natural gas for lighting, as early as 1000 B.C. These early uses were sporadic and of no economic significance. Fossil fuels did not become a major source of energy until machines running on coal, gas or oil were invented (including machines using these fuels to generate electricity). Wood, for example, was the most important fuel until 1880, when it was replaced by coal; coal, in turn, has only recently been surpassed by oil in this country.

"Once in full swing, fossil fuel consumption has accelerated at phenomenal rates. All the fossil fuels used before 1900 would not last five years at today's rate of consumption.

"Nowhere are these rates higher and growing faster than in the United States. Our country, with only 6 per cent of the world's population, uses one-third of the world's total energy input; this proportion would be even greater but for the fact that we use energy more efficiently than any other countries."

Did the Admiral's figures surprise you? They certainly surprised me when I first read them. And while his statistics refer to sources of energy for all purposes, it takes little imagination to realize that a sizable portion of that energy now goes into the 58,500,000 homes of this country. And much of that sizable portion is devoted to heating those homes. Exactly how much, is not known. We estimate that an enlightened public and a number of progressive builders have taken steps to provide enough insulation to bring about substantial fuel conservation and comfort in about 20% of these houses. We do know that 80% of them have oversized heating equipment. We can estimate, with reasonable accuracy, that if enough insulation were installed to reduce present heating energy consumption by no more than 15% in the remaining 80% of these homes that are uninsulated or poorly insulated, we could heat all the homes that will be built in this country for the next six years on the energy saved.

This vast, unnecessary loss is regrettable, but it is not without its opportunities. Uninsulated houses and oversized heating equipment offer a substantial replacement market to an industry awake to the advantages of adequate insulation and the properly sized equipment it makes possible. We've said before, there is a certain wry humor in electric heating and cooling, both very new and very vigorous, being the first in all these years to subscribe to the old, old story of adequate insulation.

And it is an old, old story. Let's go back to the 1880's, when, Admiral Rickover said, wood was just giving way to coal as the most important fuel.

SHOW SLIDE 1
This is a page from the Scientific American of April 1887. That's almost 75 years ago. The caption reads, "floors, roofs, partitions, and side walls filled with mineral wool". This article mentioned even then the identical benefits that are stressed today...winter comfort, summer comfort, economy, and fire protection.

It's important to realize that there has been no change in the promotion of these fundamental principles since the beginning.

But while the principles remained the same, many unique applications were found for them which slowly created considerable homeowner interest in insulation in the years that followed.

SHOW SLIDE 2
At first, like so many new products, insulation found its way into the better homes of the Nation. This is typical of that kind in 1882.

SHOW SLIDE 3
And the endorsement of prominent citizens made the acceptance easier. Even President Grover Cleveland came to our aid back in those days.

SHOW SLIDE 4
The possibility of fire protection afforded by incombustible insulation had always been of major interest. The caption of this picture is "Washington's Home, Mount Vernon, Virginia. Fire-protected by mineral wool on advice of National Bureau of Standards on the basis of fire tests made in 1923." Practically every other major shrine in the Nation had the same thing done to it for the same reason.

SHOW SLIDE 5
The insulation industry began early working with farmers as to how insulation would benefit their livestock. This is one example. Other work was done with apple and potato storage, the effect of insulated barns on winter milk production. Farmers were among the first to use insulation on a broad scale.

SHOW SLIDE 6
And the early days included some research on principles that were to prove useful later on. Here's one: "How Long Will a House Remain Warm With its Heating Plant Out of Commission". The answer was (and is) for an extremely long time if it was properly insulated.

SHOW SLIDE 7

And insulation found its way into the mobile home field early...and in a grand fashion, if this is a typical example. This, believe it or not, is a prewar version, for use in the Arctic. Notice the model of the automobile along side it. There was 4" in the ceiling, wall, and floor of this monster.

SHOW SLIDE 8

And a long time ago the insulation interests turned to the possibilities of "home modernization", although it didn't have that name back in those days. This picture shows the reconstruction of a 200-year old farmhouse, remodeled and insulated. Incidentally, the new version pictured boasted of a "combination electric and wood-coal" burning stove on each floor.

FADE SLIDE

Those pictures were pretty typical of how the insulation story was told from about 1880 until 1940. It was a struggling industry in those years. There were only a few manufacturers. There were no standards to speak of. Practically all of the insulation was of the "loose fill" type, and was packed or poured into the space by hand (there must have been some tough hands in our industry). Batts and blankets were just appearing on the scene.

But those that were in the insulation business were a determined, imaginative crew. They had long ago determined insulation's benefits...winter comfort, summer comfort, economy. They tried to find ways to dramatize that simple story. But it was slow going, because only individual members of the public seemed interested, and there were a lot of individual members of the public even in those days.

It was with the coming of World War II that the public really became interested in insulation on a nationwide scale, and people everywhere became very familiar with what insulation would do...for insulation was everywhere...in everything.

SHOW SLIDE 9

The vivid, varied background of war provided many uses for insulation and many opportunities to tell the true story of insulation to the nation...and the industry made the most of all of them. This picture is titled: "Mineral wool insulation in an average size oil burning house would relieve enough tanker space to provide gasoline for the flight of an American bomber from England to Cologne and back".

SHOW SLIDE 10

And the public really learned what insulation would do in commercial buildings to help with the war effort. And finally, the government stepped in and made insulation mandatory in all new homes...setting a maximum heat loss of 66 Btu per sq. ft. per hour. Originally it was designed to save metal by making smaller heating units possible. But the major emphasis quickly switched to fuel conservation with the coming of fuel transportation problems.

SHOW SLIDE 11

After sixty years of looking for a listener...the industry found the whole Nation willing to listen to its story. It fairly outdid itself, and for its efforts, received a citation from the Office of War Information.

More important, to be sure that adequate insulation was available to anyone who would use it, the government declared the industry essential.

SHOW SLIDE 12

And the government kept pounding away at the public to insulate with posters like this.

FADE SLIDE

There is little doubt that the four war years did more to promote a public understanding and acceptance of insulation for homes than had been accomplished in the previous sixty years. At the end of the war the insulation industry found itself in this position:

AS ASSETS:

1. Most of the public had heard about insulation. Most realized that if it were installed in their homes, their fuel bill would be less.

2. A lesser number...but some...realized that in addition to fuel savings, they would enjoy considerably more comfort.

3. The Federal Housing Administration had adopted the War Production Board's 66 Btu regulation and converted it into a permanent Minimum Property Standard (MPS). True, it called for no more than about one inch of insulation in the ceilings for most of the Nation. But it was the first requirement for insulation in the history of the industry.

4. The industry had worked out a pneumatic method of installing insulation in side walls and ceilings...and it had passed a long and rigid test.

5. The quality of the industry's products was much improved.

AS LIABILITIES, THE INDUSTRY STILL HAD THESE:

1. The almost complete lack of recognition by any major fuel-supplying industry...or heating equipment industry.

2. The possible danger that the newly acquired FHA minimum would be construed by builders and the public as an adequate amount of insulation.

Since the industry had acquired five actual assets against only two possible liabilities, it was far from discouraged. Back to work it went, taking steps to immediately convert the tremendous public awareness of insulation created by the war to active interest in insulation's role in the Nation's postwar construction.

SHOW SLIDE 13

The principles were the same as always, but some new applications were being mixed with the old: The Industry Engineered House, along with the old familiar WINTER ECONOMIES AND COMFORT......and

SHOW SLIDE 14

SUMMER COMFORT AND AIR CONDITIONING, along with the old BUILT-IN FIRE PROTECTION. The public reception was better...there were new fields ahead.

SHOW SLIDE 15

In the middle 40's the insulation industry became more than a little interested in the possibilities of electric house heating. Our publications carried such stories as this: INSULATED ELECTRIC HEAT. This particular heating system shown advertised itself as "a furnace room no thicker than a sheet of cardboard".

SHOW SLIDE 16

In the interests of more intelligent and accurate research in behalf of insulation, the industry turned to surveys about what the public wanted from new heating systems. This is one of the earlier surveys of this kind, conducted by American Home Magazine and widely distributed by the industry. The figures in the green block represent answers to the questions: "What do you consider the most important factors in selecting a heating system? Please list in order."

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The order of the answers to those questions will come as a surprise to some of you. In the first choice column, COMFORT & WARMTH, led all other preferences with an overwhelming 63%. Low initial cost had 1% and low operating cost had 6%.

Look at the various choices in the columns that list second, third, fourth and fifth choices.

One of my friends in the electric heating industry is fond of saying that in the transition from wood to coal, coal to oil, oil to gas, in each instance the homeowner was paying more for the new fuel but didn't object because he was getting a heating system that was better. It would seem these figures support my friend's philosophy....and that a newer system, providing greater comfort, does not necessarily have to be cheaper -- or even as cheap as commonly used systems....to win public approval.

SHOW SLIDE 18

In the early 50's the industry became interested in a heating experiment that was considerably advanced for those days....and for that matter, for these days. The subject was solar heating. That insulation would play a vital part in the success of a solar heating project was willingly conceded at the beginning.

Thus, you might say, the first heating fuel to actually recognize the merits of insulation came from heaven. About that time it was rather hard to find one on earth. This is the research residence at MIT. It is still being used for the experiment.

SHOW SLIDE 19

Perhaps the most famous research project on residential air conditioning ever carried out was the Air Conditioned Village experiment of 1954. Twenty-two houses, built by members of the National Association of Home Builders, with various types of equipment and various amounts of insulation, were analyzed while families were actually living in them. The Village was in Austin, Texas, and the climate there is tough.

Volumes of information came out of the project. Where insulation was concerned, the conclusions were that for the builder, each dollar spent on adequate insulation for air conditioning above the current MPS saves $1.82 in otherwise required equipment...a net savings of 82¢ per dollar.

For the owner of the home, each dollar's worth of insulation above the current MPS reduces average annual heating-cooling costs by 63¢. These were the findings of the Chief Analyst of the Village, which were widely circulated by the insulation industry in this book.

More than anything else, this project established the necessity for insulation in air conditioned homes.

SHOW SLIDE 20

This little red book marked the beginning of a completely new era in the insulation industry. Written in 1955, largely as a result of the deductions we made from the Air Conditioned Village project just mentioned...it rapidly became a best seller. There are more than 400,000 copies of it in use around the world.

It was unique for two reasons:

1. It was written for the first heating fuel industry that ever acknowledged that insulation should be a fundamental part of their heating system.

2. An attempt was made to recommend standard insulating practices for electrically heated homes. This was the still-too-well-remembered...

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... 6-4-2. Six inches of insulation in the ceiling, four inches in the wall, and two inches in the floor. Its acceptance was amazing. Perhaps the timing with the first real push of electric heating was responsible for its acceptance, but whatever the reason, when time came to clarify it in the name of accuracy, we found that phrase "6-4-2" almost impossible to bury. She's still around.

FADE SLIDE

But we did find it necessary to clarify it...simply because technological changes within the industry made products no longer comparable on an inch-for-inch basis. A common denominator was needed. We found one in what we chose to call...

SHOW SLIDE 22

... the R number. This was introduced just a little more than a year ago... and it has caught on rapidly throughout the insulation industry.

Simply stated, the R number of an insulation product indicates its installed resistance to the passage of heat into or out of a house when the insulation is actually in place in the structure...not in the carton. It takes into consideration the mass, the types of surfaces, the values of air spaces and surfaces, if they are present. It is applicable to any kind of insulation. It eliminates many calculations. It is an accurate common denominator where inches of thickness was not. And right about the time of R numbers came...

SHOW SLIDE 23

The All Weather Comfort Standard (AWCS). This was launched at the National Electrical Manufacturers Association (NEMA) Electric House Heating show in Chicago in March of last year. This time, the recommendations were the result of joint effort on the part of electric power producers, building material manufacturers (including insulation), and the makers of electric heating and cooling equipment.

SHOW SLIDE 24

It was strictly a performance standard. It encompassed any kind of construction. It made use of any kind of insulation. Its only recommendation was that the amount of heat escaping from an electrically heated house be limited to a certain amount. How you limited it was your own affair. And, conversely, it recommended that limits be placed on the amount of heat allowed to enter air conditioned houses. These recommended limitations were expressed with U-values.

And since the resistance value of typical ceilings, walls, and floors are relatively constant, it followed logically that it should be possible to manufacture insulations specifically tailored to meet the recommended limitations, or U values, of the AWCS.

SHOW SLIDE 25

This industry did just that with the previously developed R numbers. An insulation product regardless of its thickness or surface that would provide 19 units of resistance when installed in a typical ceiling would, in conjunction with the ceiling materials themselves, meet the recommended heat loss limitation (or U-value) of 0.05 ceilings. And so it was, too, with walls and floors.

By merely specifying the insulation by the appropriate R number, it was possible for a user to meet the U-value recommendations of the AWCS without further calculations.

FADE SLIDE

What has been the story of the AWCS, which is just a little more than one year old? Well, there has been plenty of debate, and you'll hear more here. And that's good. In a vigorous, growing industry such as electric heating is, there will be vigorous debate on practically any given subject. That is healthy.

But in the main, has there been a sufficiently broad acceptance of the recommendations made in the AWCS to prove that it is generally acceptable? Has there been enough acceptance to indicate that it is, all things considered, practical? Does it seem to fit into the cost facts and figures of a substantial number of different electric heating situations across the country?

We owe thanks to Electrical World magazine for the latest answers to these questions raised about the acceptance of the AWCS. That publication has just finished an extremely comprehensive analysis of the present state of electric heating throughout the Nation. It will appear in their June 7th issue. It has much to offer...including reason for optimism.

134 utilities, representing 74% of the Nation's meters, were polled on various electric heating topics. 120 of them answered the specific question: "Do you use the AWCS recommendations (R-19, 11, 13)?" And here is what the 120 said:

SHOW SLIDE 26

72.5% now use the AWCS recommendations of R-19 for ceilings, R-11 for walls, and R-13 for floors.

27.5% do not use these recommended figures, but use either a greater or lesser amount of insulation for various reasons. I must admit that even we were surprised that the acceptance has been so widespread in so short a time.

FADE SLIDE

This, then, brings us up to the PRESENT part of the story: INSULATION -- PAST AND PRESENT. Looking back, insulation appears to have been a colorful, frustrating industry in its early days. But from hand-packing ceilings in the 1880's we have come to the present...where the insulation industry now works hand-in-glove with one of the Nation's greatest producers of energy to provide comfort and economy for the users of that energy.

More progress has been made by the insulation industry in the past ten years than in the previous fifty. Probably more progress will be made in the next five years than we have made in the past ten. There will be changes made... new insulation products will appear...new uses will be found for insulation.

But the major problem is now past...the question is no longer, "Will the Nation's homes of the future be insulated?" but rather, "How much insulation will future homes have?"

We have an idea that the electric house heating industry will have much to do with that final answer.

STUDIES ON TWO ELECTRICALLY HEATED RESEARCH HOUSES

by

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Current energy demands of the United States for power, processing, and heat average approximately 100,000 billion Btu per day, 30 percent of which is required for space heating. This proportion is likely to remain constant for the next century. But total energy requirements of the United States and the rest of the world are rapidly increasing both because of booming population growth and the impact of rapid technological changes on our standards of living. This expanded demand has resulted in marked increases in the costs of oil and gas during the past three decades; yet, an increase in the efficiency of conversion has resulted in reduction in the cost of electricity. All of these fuels are now economically feasible for space heating under some conditions. Nevertheless, the costs of all forms of space heating have risen, and the consuming public has become more conscious of the need for conserving space heating energy through adaptation of properly engineered heating systems coupled with thermally efficient structures.

The past three decades have seen calculation of heating loads progress from rule-of-thumb procedures used in the 1920's when fuels were cheap and space heating comfort demands not rigid, to the present time when the public demands close control of comfort conditions and engineering provides proper analytical procedures for load calculations and system design. Accurate laboratory tests for determining thermal and mass transfer characteristics of building materials now are used routinely.

But, despite these advances, many gaps remain in our knowledge of design and functioning of heating systems when applied to structures. Individual thermal conductivities of materials used in wall sections are known, but effects of framing members and other field installation variables are not duplicated in laboratory tests. Infiltration assumptions are approximate at best. For instance, tightly constructed and well insulated structures, in which infiltration is reduced to a minimum, may require special consideration as far as moisture and odor removal are concerned.

It appears probable that heating demands of a structure are, to an appreciable extent, dictated by ventilation needs and that in tight structures, either artificial ventilation or some internal means of moisture and odor removal may be required. The actual structure to be heated either rests upon or is sunk into a mass of earth of high heat capacity and relatively high thermal conductivity.

The structure to be heated is subjected periodically to a high intensity solar radiation field and a portion of this energy is absorbed on the outside surface of the structure and a portion is transmitted through fenestration to the interior.

The outside of the structure is subjected to varying temperatures, varying wind conditions, rainfall and snowfall and solar radiation, and the inside to a variety of unscheduled heat and moisture gains. It is designed and heated that it may provide comfortable living conditions for people who live, work, and play inside; yet, we are not always certain of the effects of these living habits upon heating demands of the structure.

In recognition of these gaps in our technical information, two test houses were constructed to provide field laboratories in which answers to a number of these questions could be obtained. These houses were provided with stimulated living loads under accurate control and were fully instrumented to provide complete information on operating characteristics. A continuous record of the external environment was provided through a recording of weather conditions, including solar radiation. Soil analyses were made adjacent to the structures, and the earth's temperature variations recorded through a thermocouple well and adjacent to foundation wall.

FIELD LABORATORIES AND THEIR ENVIRONMENT

The two test houses were constructed on adjacent 120 x 135 ft. north-south-oriented lots on the edge of Stillwater, Minnesota, 18 miles east of St. Paul. They are identical except for differences in insulation. Each was constructed with a system of panel wall components[1/] with approximately 1,100 sq. ft. of living area. Figure 1 shows an aerial photograph of the houses and figure 2, a first floor and basement floor plan. The houses are north oriented. Both have approximately the same solar radiation exposure on the east, south, and west; shadow pattern photographs were taken at different times of the year to determine this point.

Figure 1.--Aerial view of houses from north side. House A is on right; House B is on left.

1/ Lu-Re-Co system of construction consists of preassembled modular 4 x 8 ft. exterior wall, window and door panels (2 x 4 studs are 24 inches on center) and roof trusses paced 24 inches on center. Conventional exterior and interior finish materials are used to complete the house.

House Construction and Heat Demand Calculations.--Both test houses are identical with the exception of differences in type and thickness of wood fiber blanket insulation as shown in Table 1. Overall heat transmission coefficients as determined by calculation (corrected for framing heat loss) and guarded hot box test are included. Basement recreation room exterior walls in each house were insulated with 5/8-inch blanket between 2 x 2 inch furring and 1/2-inch insulating plank interior finish. The exterior walls in both laundry rooms were uninsulated.

All windows were weather-stripped wood sash with welded double glass. A removable third pane was installed from the exterior with clips. Window and door areas were approximately 15 percent of gross wall area. Figure 3 presents a cross section drawing of the construction and insulation used in both houses. The living-dining room and three bedrooms were furnished with major pieces of furniture to occupy space and provide heat storage capacity.

Simulated Occupancy.--Demands made upon a heating system are dependent to an appreciable extent upon living habits of the occupants of the space. For this reason, it is difficult to arrive at rational conclusions from field data. It was, therefore, decided that a controlled, simulated occupancy would be defined and installed in order to provide heat and moisture supplements normally added by occupants.

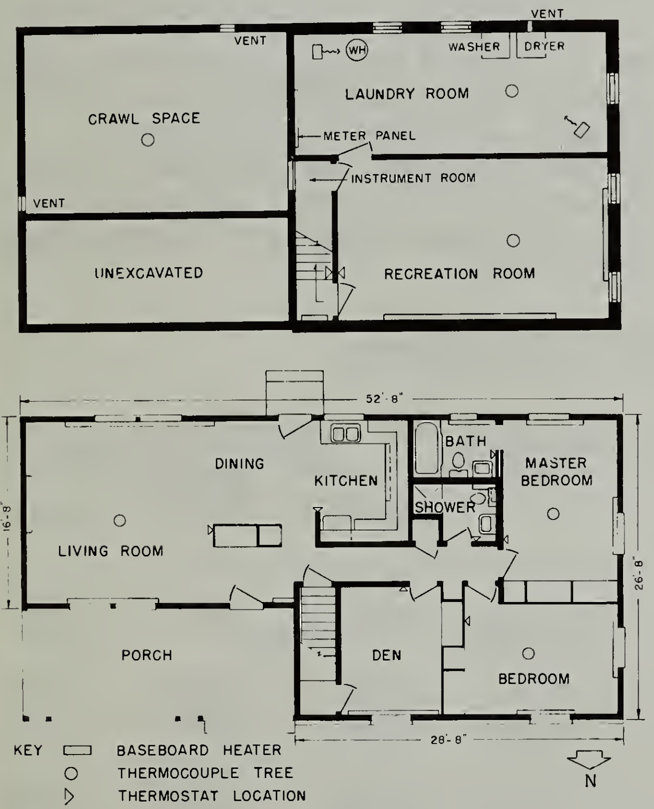

Figure 2.--Plan of first floor and basement showing location of baseboard heating units, thermostats, and thermocouple "trees"

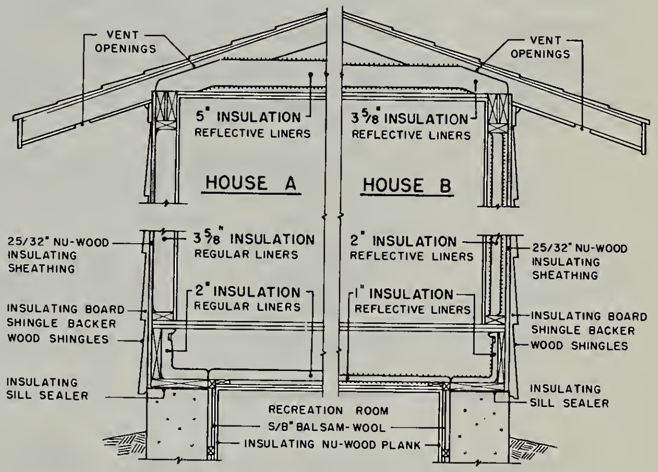

Figure 3.--Cross section drawing showing construction details and ceiling, wall and floor insulation in each house.

TABLE 1.--Schedule of insulation used in each house with calculated and hot box test "U" values for balsam-wool blanket insulation

House	Construction	Thickness	Liners	"U" Value	
				Calculated	Hot box test
A-----	(Ceiling-----	5 in.	Reflective	0.049	0.046
	(Walls-------	3 5/8 in.	Regular	.062	.057
	(Floor-------	2 in.	Regular	.078	.082
B-----	(Ceiling-----	3 5/8 in.	Reflective	.060	.056
	(Walls-------	2 in.	Reflective	.062	.066
	(Floor-------	1 in.	Reflective	.063	.071

1/ Calculations corrected for heat loss through framing members (10 percent for ceiling and floor joists, 15 percent for wall studs, plates, and headers).

A family of four consisting of two males, both old enough to be considered adults, one adult female, and one child was postulated and heat and moisture gains to the space from these occupants based upon data available in the 1960 ASHRAE GUIDE. It was assumed that the family slept 8 hours in the house and averaged an additional 7 hours of more active life in the living space. Simulated loads, as shown in Table 2 were actually distributed over a longer period of the day. Total heat supplied by the occupants was provided through electrical cone heating elements and a proportion of this heat translated to a moisture load by operation of a humidifier in which sensible to latent heat was translated by absorption of heat from the air.

TABLE 2.--Heat simulation for occupancy

Location of simulator	Period of operation	Total heater operation per day	Connected load	Heat simulation per day		
				Sensible	Latent	Total
		Hr.	Kw.-hr.	Btu	Btu	Btu
Living Room	8 a.m.-11 p.m.	15	0.150	5,759	1,920	7,679
Kitchen	8 a.m.-11 p.m.	15	.100	3,840	1,280	5,120
Master Bedroom	11 p.m.-7 a.m.	8	.150	3,072	1,024	4,096
Bedroom	11 p.m.-7 a.m.	8	.100	2,048	682	2,730
Den	11 p.m.-7 a.m.	8	.075	1,536	512	2,048
Total Heat Input, Btu/Day						21,673

Operation of refrigerator, range, freezer, television set, lights, and miscellaneous electrical appliances were also simulated through the operation of electrical cone heaters of appropriate size. However, the electric dishwasher, water heater, shower bath, clothes washer, and clothes dryer were actually operated with cycling controlled by a programmer.

Table 3 presents a summary of simulated utility loads for this family of four persons as selected for these tests. The first column of this table shows the simulated or actual appliance load, and column 2 shows the period of use per day. Column 3 shows the actual connected load of the unit and column 4, the kilowatt hour per day for the actual or simulated appliance. Column 5 provides explanatory comments on the basis for simulation. References at the bottom of the table indicate the source material upon which these assumptions were based.

TABLE 3.--Utility load simulation for family of four 1/

Simulation	Total use per day	Connected load	Total consumption per day	Basis for simulation
		Kw.	Kw.-hr.	
Actual operations:				
Washer	50 min.	0.30	0.25	7 complete wash cycles per week of 8# canvas cloths washed each cycle. 2/, 3/
Dryer	55 min.	4.24	3.90	7 complete drying cycles per week of 55 min. per cycle. 8# wet canvas cloths taken from washer dried each cycle. 3/, 4/
Dishwasher	50 min.	1.02	.85	Average daily use estimated at one load per day. 2/, 3/, 4/
Water Heater	Automatic	2.60	14.16	Operates automatically to supply approximately 60 gal. of 150°F. water daily (37 gal. simulating baths, 4 showers per day, lavatory use and losses; 7 gal. for dishwasher; 16 gal. for clothes washer). 1/, 2/, 3/, 4/, 5/

TABLE 3.--Continued

Simulated operations:				
Refrigerator	12 hr.	.10	1.20	Total daily kw.-hr. consumption. Based on 50% operation and equals average monthly consumption.4/, 5/
Freezer	Continuous	.25	1.80	Total daily kw.-hr. consumption equal to 1/4 hp. freezer operating 1/3 of time and equals average monthly consumption.2/, 4/, 5/
Range	100 min.	2.00	3.40	Total daily kw.-hr. consumption for 100-min. operation equal to average monthly use for large cities.2/, 4/, 5/
Television	6 hr.	.15	.75	Total daily kw.-hr. consumption equals 6 hrs. average daily use.4/
Lights and Misc.	Continuous	.14	3.36	Total daily kw.-hr. consumption for misc. appliances, (e.g., toaster, mixer, radio, clock, etc.) and lighting.4/

1/ ASHAE Guide 1959, Chapter 56
2/ Association of Edison Illuminating Companies, "Report of Load Research Committee 1957-1958," April 1959
3/ Data on manufacturers' published figures and experiences of sales personnel submitted by Minnesota Power & Light Company
4/ Potomac Electric Power Company, "Elements of Load," April 1959
5/ Association of Edison Illuminating Companies, "Report of the Residential and Rural Loads Subcommittee," June 1959

ACTUAL OCCUPANCY

During the first winter (1959-60), both houses were operated with the simulated "invisible families." This was done to determine under identical conditions the effects of variations of insulatiom in Houses A and B. Once these tests had been made, it was then possible to operate during the second winter under differing conditions in the two houses; therefore, an actual family, shown in figure 4, replaced the "invisible" family in House A. No attempt was made to control the living habits of the actual family and it was recognized that no single family could be "average." However, it was expected that any differences in operating results could be analyzed and explained. Tests were continued the third winter with actual families living in both houses.

Figure 4.--Actual Family in House A

INSTRUMENTATION

Measurements of heating demands and inside and outside environment were provided by (a) an electrical power input measuring system, (b) a temperature measuring system, and (c) a moisture measuring system. Each will be discussed in turn.

Electrical Energy Input Measuring System.--Electrical energy consumption was recorded in each house by nine individual room meters and by two demand meters. The living room, kitchen, northwest bedroom, southwest bedroom, den, bath, and shower on the first floor were metered individually and, in addition, meters were provided for basement laundry room and basement recreation room (including stair well). All individual room meters were calibrated to an accuracy of ± 0.10 percent.

Temperature Measuring System.--A total of 303 copper-constantan thermocouples were used to define temperatures inside and outside houses. Of these, 78 were recorded automatically every 24 minutes and 145 were read manually each week and were controlled by selector switches. An additional 80 thermocouples,

installed to determine specific conditions, were read periodically when information was needed. All continuous recordings were made by means of two recording potentiometers and the manual readings by means of a portable potentiometer connected to a manually actuated stepping switch.

Room temperature gradients were measured in the living room, southwest and northwest bedrooms, at the floor, 3 and 60 inches above the floor, 3 inches below the ceiling and at ceiling surface. In addition, recording resistance thermometers with a nickel bulb located near room thermostats provided continuous strip charts of room air temperatures in each house. All air thermocouples were shielded from radiation effects by means of concentric foil covered rings which permitted free air circulation but eliminated warm and cold radiation effects from window and wall surfaces.

Moisture Measuring System.--Continuous readings were made of relative humidity in the living spaces of both houses by two recording hygrometers. Relative humidities were checked weekly with a sling psychrometer in all rooms including attic and crawl spaces. In addition, periodic moisture measurements were made in the wall plates below the kitchen sink, shower room, northwest bedroom, and in the crawl space in the plate located above the concrete block. Moisture probes were permanently imbedded in plates at all measuring points and a Delmhorst moisture meter was used to record moisture contents.

OPERATION PROCEDURES

Although it was recognized that there was some merit in operating both houses under constant conditions throughout the winter, it was felt that it was more desirable to explore various operating combinations so that a wider variety of data might be obtained. For this reason, a varying schedule of operation was followed and for the period from October 31 to June 1 the houses were operated under conditions for full load simulation 37 percent of the time; under heat simulation, 15 percent of the time; and under conditions of no simulation load, 48 percent of the time. During 55 percent of the heating season, the houses were operated with triple glazing on windows and for the remaining 45 percent of the season with double glass.

For the initial 2 months of operation or approximately 25 percent of the heating season, houses were operated with the living room maintained at 72°F.; baths, at 75°F.; bedrooms, at 68°F.; and stairway and basement, at 65°F. During this period, heat distribution characteristics were determined and following this, all rooms, with the exception of basement and stairway, were set at a constant room temperature of 70°F. The basement was heated to 65°F. in 2-hr. cycles each day for a portion of the time, continuously on 24-hr. cycles for another period, and no heat was supplied during a third period. A complete schedule of the different phases of operation together with an analysis of results will be presented in a subsequently to be prepared paper.

It was recognized that it would be impossible to artificially simulate

infiltration through door openings and for this reason a schedule of 12 door openings for entrance to or exit from the houses were provided manually. These openings were according to a fixed schedule and a logbook was provided to record these and all other manual activities to which the houses were exposed. During one period of operation, the door openings were increased to 24 per 24-hr. period and during a few brief periods when inspection of the houses occurred, a much higher number of entrances and exits were recorded. Particular care was taken to obtain an equal number of door openings and entrances to each house. It was recognized that the ventilation to which a house is exposed is, to a great extent, dictated by the living habits of the occupants, and that this varies markedly between families. In the present tests, door openings to which each house was exposed defined the simulated living habits for this particular simulated family.

Additional ventilation was provided by operation of the kitchen exhaust fan during the periods of simulated cooking operations and the ventilation fans for the shower room during the periods when the showers were in actual operation. Further, it was recognized that under actual operating conditions when very high humidities are experienced, ventilation is usually provided by the occupants in order to alleviate these conditions. This ventilation is normally provided by additional door or window openings. In the simulated operation, a humidistat was installed to operate the central shower fan upon demand whenever predetermined excessive humidities were experienced. Doors extending from floor to ceiling permitted good circulation of air when the fan operated.

Each house was inspected daily and these inspections included checking operation of the programmer, circuit breakers, humidifiers, all appliances, and all recording equipment. All electric meters were read, and the camera equipment used to record the midnight meter readings was checked and the film advanced. All water consumption meters were read; a load of clothes washed in the electric washing machine was shifted to the dryer. Drapes and shades in each room were inspected and any window condensation noted. Operation of dishwasher, range, fan, and the shower and shower fans were all checked.

The total amount of 1.2 gallons of water was introduced daily into each house by the humidifier to simulate the calculated 0.96 and 0.24 gallons of water given off by occupants and cooking, respectively.[2] Daily consumption of all outside service meters were also read. Snow depth, if any, adjacent to the house on all sides was recorded. All vents were checked to make certain that they were not obstructed. An exact schedule of operation was provided, with each item to be accomplished in sequence in order that there would be no variations from day to day.

2/ "Research in Humidity Control," Bulletin No. 106, Engineering Experiment Station, Purdue University. 1948.

OBJECTIVES

Objectives may be subdivided as (a) heat loss studies, (b) temperature studies, and (c) moisture studies.

Heat Loss Studies.--One of the principal objectives of the first winter's studies was to determine actual energy requirements and operating costs under a variety of defined and controlled inside conditions and a complete monitoring of the outside environment. These tests have permitted study of ceiling, wall, and floor insulations and the effects of a variety of weather conditions including solar radiation and wind speed and direction upon the energy consumption of individual rooms as well as the complete houses. They have also provided a comparison of actual heat loss requirements with calculated heat losses.

Temperature Studies.--Detailed temperature measurements have permitted studies of room air temperature stratification and a comparison of wall temperature gradients with calculated gradients under different operating conditions. These studies include investigation of crawl space and attic air temperatures under different ventilation conditions and basement area and ground temperatures with seasonal variations.

Moisture Studies.--Conducted to determine upper limits of indoor relative humidity as a function of the external environment, and field studies of effects of double versus triple glazing.

RESULTS OF TWO WINTER STUDIES

Cumulative Energy Consumption.--An analysis of the cumulative energy consumption for the first winter's operation showed House A required 5.5 percent (Fig. 5) less energy supplied to the first floor heating system than did House B. However, both houses had additional amounts of electrical energy supplied through appliances and heat energy by the supposed occupants. If this energy, together with the free energy supplied by solar radiation, is taken into consideration, then the difference in total energy supplied to House A was more nearly 4.5 percent less than that for House B. These field tests bore out very closely the laboratory tests of the heat transfer coefficients for the wood fiber insulating materials used.

Calculated Heat Loss vs. Measured Energy Consumption.--The actual energy supplied to the heating system alone was less than the calculated total heat requirements by 29.3 percent during the winter of 1959-60 and 31.8 percent during the winter of 1960-61 as shown in figure 6. These percentages were for the period November 1 to May 1, and the differences represent the amounts of heat supplied principally by the appliances and occupants and, to a lesser extent, by solar radiation. Interestingly, if the mild winter periods before November 1 and after May 1 were also included, these percentage figures would be even greater since during such mild periods, the appliances, occupants, and solar radiation often supply all of the heat required for heating the structure.

Actual Energy Consumption.--During the winter of 1960-61, the actual family lived in House A and the simulated family in House B. The utility requirements for the simulated family were based upon the average requirements of a large bumber of families. However, the actual family living in House A, as expected, varied from the "normal." Their use of utilities was somewhat greater than average; nevertheless, the energy supplied to the heating system and utilities was approximately the same for both Houses A and B, as illustrated in figure 7.

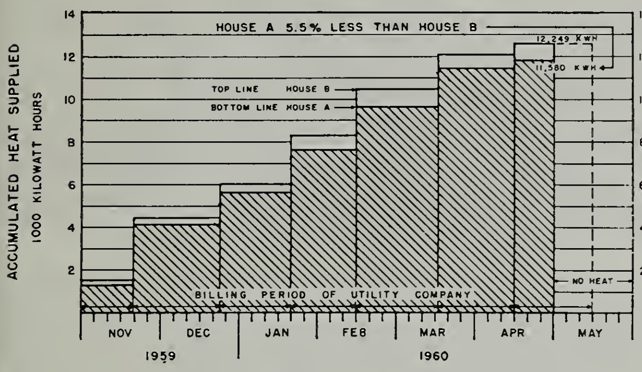

Figure 5.--Cumulative energy consumption in houses A and B.

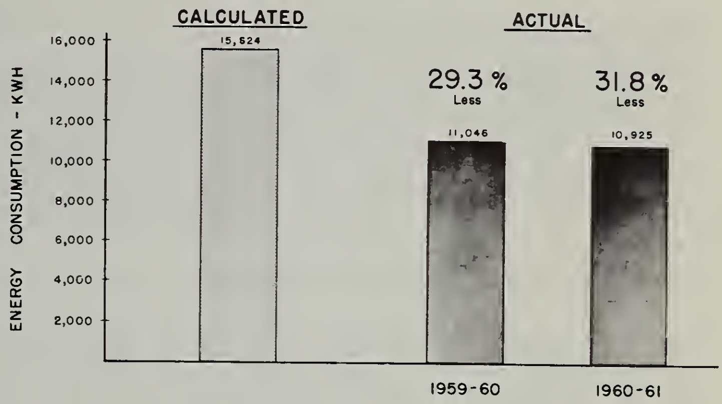

Figure 6.--Comparison of calculated heat loss and measured energy consumption.

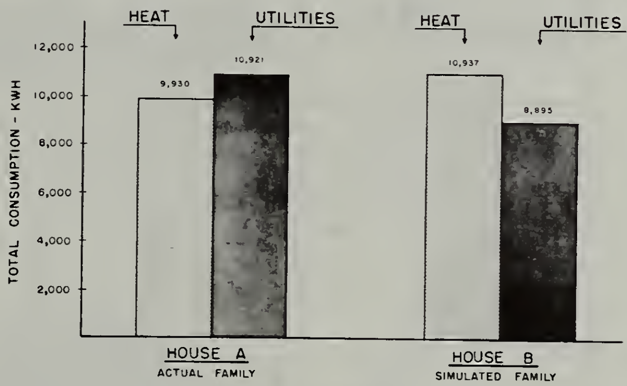

Figure 7.--Energy consumption the second winter.

Effect of Low and High Solar Radiation on Demand.--As a part of the test program, the total energy requirements for heating and utilities were obtained for these residences under a variety of operating and external conditions, and daily demands may be represented by charts. These charts show the energy requirements in half-hour increments over 24-hr. periods with an inside temperature of 70°F. unless indicated differently. The light areas represent the actual heating demand and the dark areas the additional energy supplied for the simulated occupants and appliances.

The demand chart shown at the top of figure 8 for January 1, 1960, shows the energy requirements during a period when there was no attempt to simulate either heat or moisture loads; the incident solar radiation was quite low (100 Btu/sq.ft./day on a horizontal surface); the average wind velocity was 8 to 9 miles per hour, and the outside temperature varied in the narrow range between 24°F. and 29°F. The preceding day was one during which the outdoor temperature was also in this range so that the building had had an opportunity to reach thermal equilibrium conditions.

In contrast, on March 10, 1960, the incident solar radiation was quite high (1,460 Btu/sq.ft./day horizontally and 2,180 Btu/sq.ft./day vertically). This demand chart (Fig. 8, bottom) is also under conditions of no simulated load and with no basement heating requirements. The dip in energy demand around noon was caused some by the slightly increased outdoor temperature and to a much greater extent by the increased incident solar radiation. This energy, passing through the south-facing windows of the house, was trapped as in a greenhouse and materially reduced the energy requirements for heating.

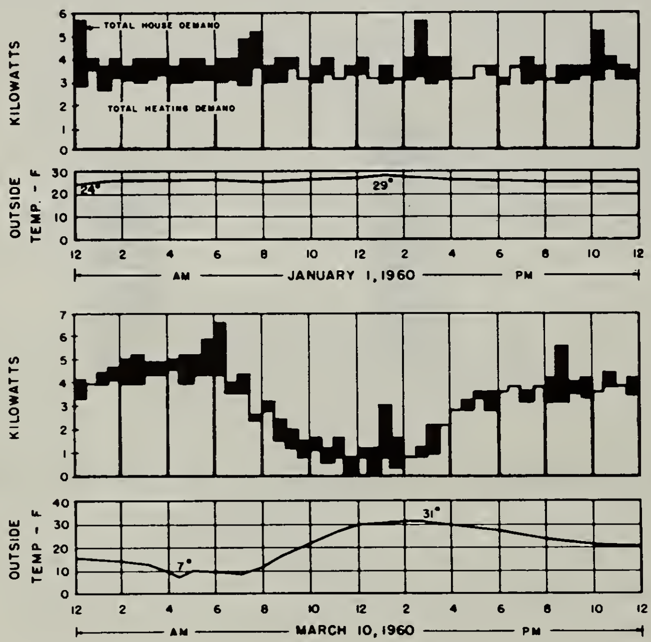

Figure 8.--Heat and utility demand on sunny and cloudy days.

Energy Demands of Actual and Simulated Occupancy.--The demand charts for December 19, 1960, were taken during the second winter's operation. The upper chart of figure 9 represents the total energy during simulated occupancy in House B. The outside temperature ranged from 3°F. to 14°F.; the incident solar radiation was low with only 210 Btu/sq.ft./day on a horizontal surface. The lighter areas on the chart again represent the actual heating demand and the dark areas the additional energy supplied for the simulated appliances and occupants. The peaks shown are associated with such simulated activities as cooking, washing, drying, and baths.

However, on the same day, the actual family living in House A deviated far from the assumed average schedule of appliance operation. The actual family washing and consequent hot water demand and energy for the clothes dryer was concentrated on this particular day, resulting in heavy appliance and basement heating demands shown by the lower chart of figure 9.

Effect of Thermostat Change on Heat Demand.--Much heavier than normal energy demands will occur when a thermostat setting is increased appreciably. On March 28, 1961, when the actual family in House A was on vacation, air infiltration studies were conducted. On this mild day when the outdoor temperature averaged 30°F., the thermostat setting was increased at 9:30 a.m. from 60°F. to 70°F. where it remained until 4 p.m. The total demand to supply this higher temperature resulted in an increased energy demand of some 600 percent, as shown in figure 10. It should be noted, however, that even this increase by no means taxed the power supply to the residence since the total demand was still only 25 percent of the rated service capacity.

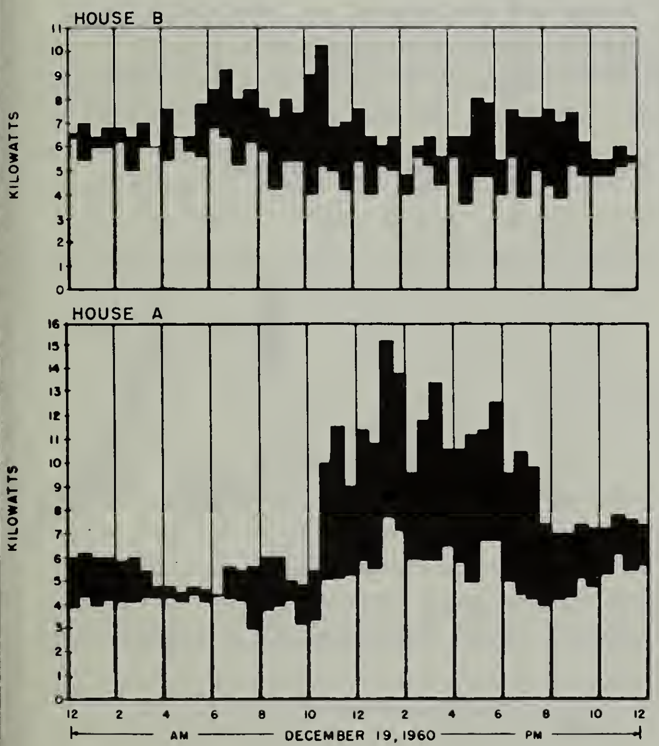

Figure 9.--Actual and simulated occupancy heating and utility demands.

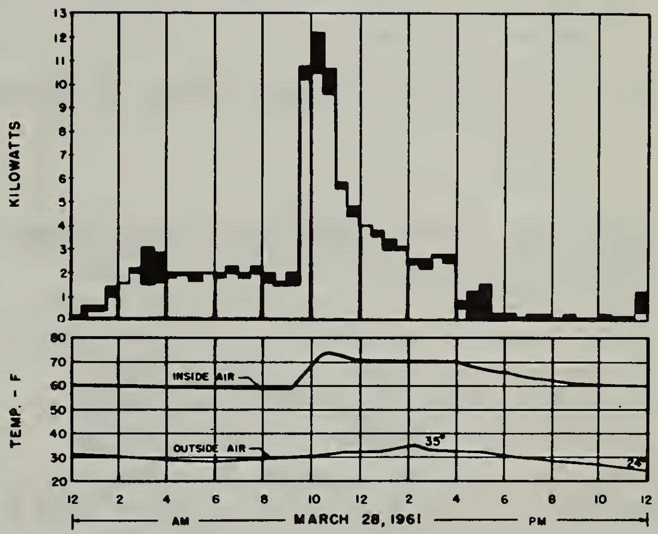

Figure 10.--Effect of thermostat change on heat demand.

Effect of Subzero Weather on Energy Demand.--During the third winter's tests, the temperature on four successive days was below zero most of the time with dips below -20°F. Figure 11 shows the greatest heat demand at 10 a.m. on January 17, 1962, was 11.2 kilowatts, which was about 78 percent of the connected heating capacity including the laundry room (heated to 65°F.). The sharp decline in demand at 11 a.m. on January 17 was caused by the bedroom heaters being turned off when the rooms were ventilated. High solar radiation on the two sunny days resulted in a reduction in heat demand during the middle of the day in spite of zero degree weather.

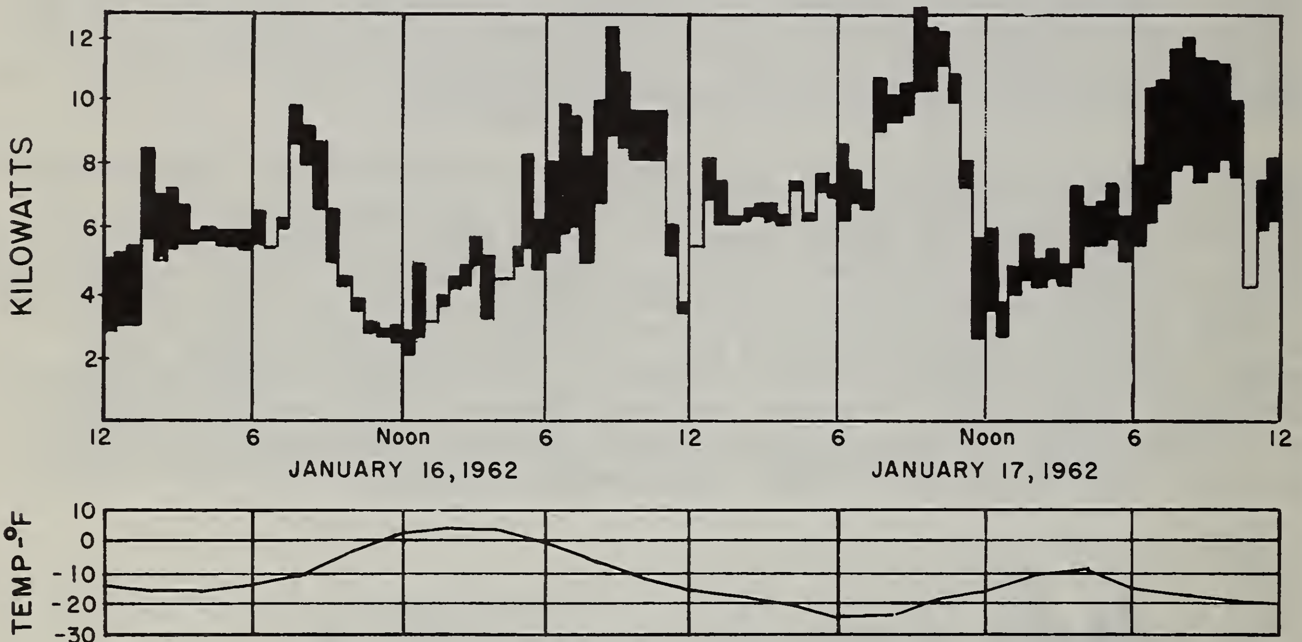

Figure 11.--Influence of subzero weather on heating demand.

Effect of Power Interruption and Ventilation on Demand.--On February 16, 1961, a power interruption was simulated by cutting off the energy supply to the heating system. At 6 p.m., another unusual load was simulated by opening four windows in the living room, two in the northwest bedroom, and two in the southwest bedroom for a period of 20 minutes in order to ventilate the house. The effects upon both the inside air temperature and the heating energy demand are clearly evident in figure 12.

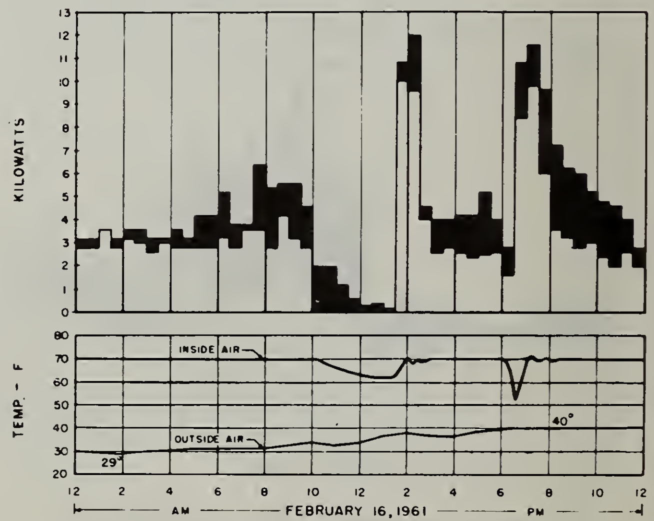

Figure 12.--Effect of power interruption and ventilation on demand.

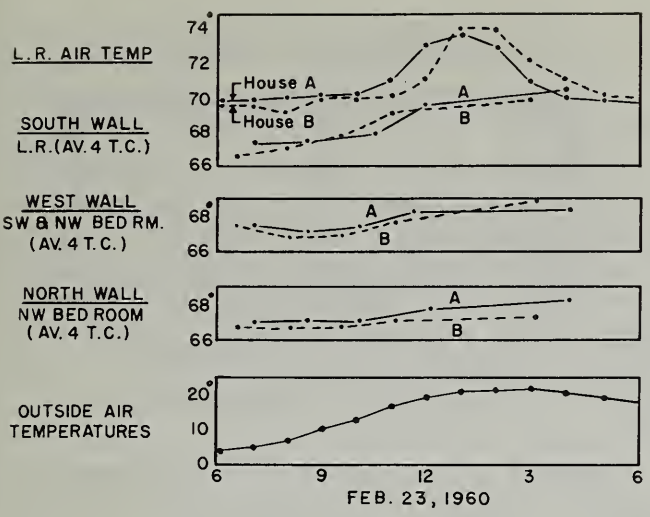

Figure 13.--Wall surface temperature in relation to living room and outside ambient temperatures.

First Floor Interior-Wall-Surface Temperatures.--Inside-wall temperatures are an indication of the performance of the wall insulation. Figure 13 shows that on February 23, 1960, the inside surface temperatures of the north and west bedroom walls were fairly constant between 67° and 68°F.--only 2.3° lower than the air temperature. The south wall, however, and particularly the living room air temperature were affected by solar radiation (1,462 Btu/sq. ft./day on the vertical surface) that both impinged on the walls and passed through the south-facing windows. As a result, the south wall temperatures rose to 70° and the living room air temperature to 74°. The wall temperatures in both houses were practically the same, indicating approximately equal performance of the two types and thicknesses of Balsam-Wool insulation.

First Floor and Basement Heat Energy Consumption.--During a period of about 40 days in the winter of 1960-61, the basement was heated continuously to a temperature of 65°F. and the first floor to 70°F. The daily energy demand for the first floor responded inversely to the outdoor temperature, but the basement heating demand was comparatively constant. The stabilizing effect of the mass of earth surrounding the basement area is thus evident in figure 14, yet approximately 40 percent as much heat was required to heat this small basement area as for the entire first floor of the residence. Insulation of the laundry room walls would have materially reduced this figure.

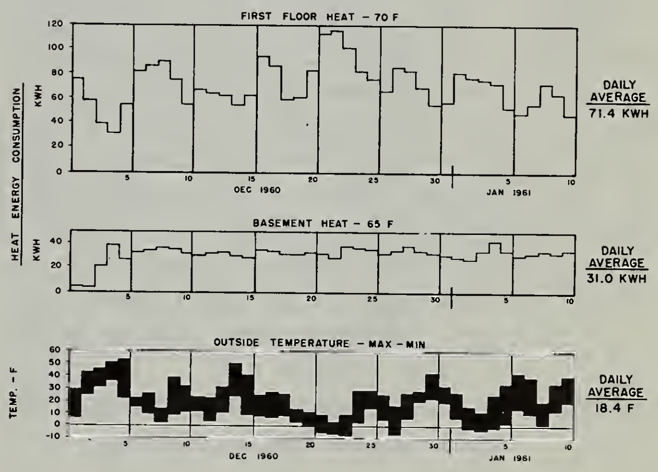

Figure 14.--Relation of first floor and basement heating demands.

Basement Wall Insulation Reduces Heat Energy.--The effect of basement wall insulation is shown in figure 15 by analysis of data during a continuous basement heating period April 7 to 25, 1960. Both the laundry room with uninsulated walls and the recreation room with insulated walls were kept at a temperature of 65°F. The average surface temperatures of the walls of the laundry room were approximately 60° while the insulated recreation room walls were 63.5°. Even more important, with about the same amount of outside-exposed wall area, the uninsulated laundry room required 35 percent more heat than the insulated recreation room. This is a conservative figure since heat contribution from the hot water heater, clothes washer, and dryer located in the laundry room was neglected.

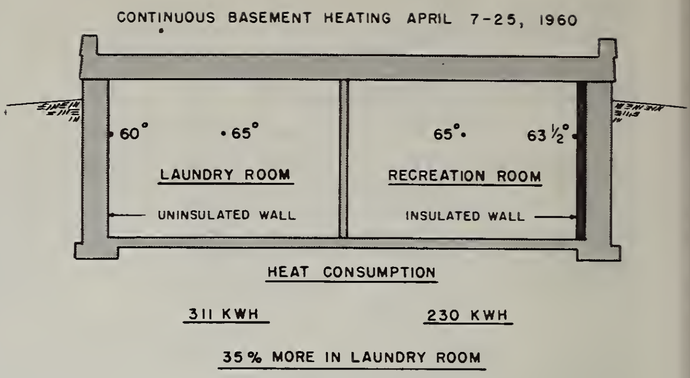

Figure 15.--Temperature and heat demands in basement.

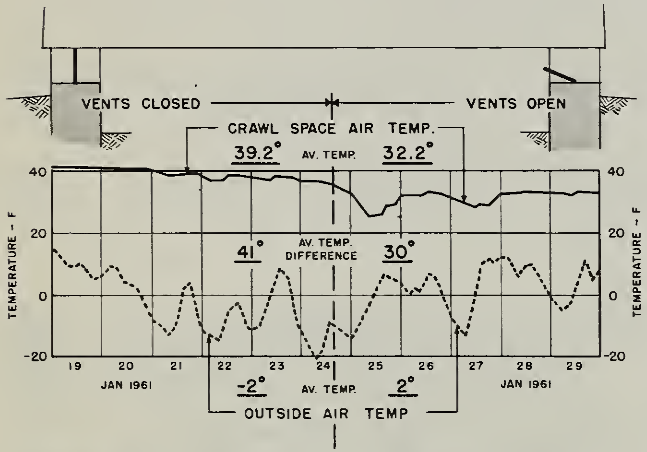

Figure 16.--Effect of ventilation on crawl space temperatures.

Crawl Space Air Temperatures.--During several periods including January 1961, the crawl space air temperatures were recorded with the vents both opened and closed. Figure 16 shows that with the vents closed during the period January 19 to 24 the average temperature difference between the crawl space and outdoor air temperature was 41°F., but with the vents opened from January 24 through January 29, this difference was reduced to 30°. Polyethylene (4 mil.) vapor barrier, which covered the crawl space earth, did an effective job in maintaining low humidity in this space.

Window Surface Temperatures.--The inside-surface temperatures of north windows were comparatively constant, being affected primarily by outdoor air temperatures, whereas south-window temperatures fluctuated owing to some heat absorption from solar radiation as well as outdoor temperature. Figure 17 illustrates that surface temperatures of double glazing were much lower than that for triple glazing (welded double glass plus a third pane applied to the wood sash from the outside). Since the maximum relative humidity in a room depends upon the lowest surface temperatures of any of the bounding surfaces, triple glazing permits higher inside relative humidities (40-45 percent even in 0°F. weather) than does double glazing.

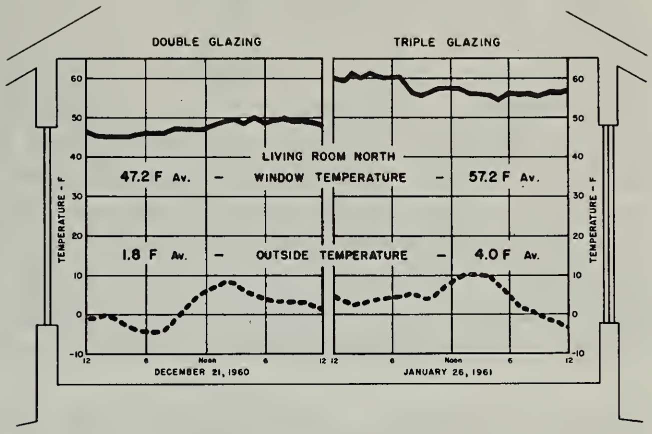

Figure 17.--Surface temperatures of double and triple windows.

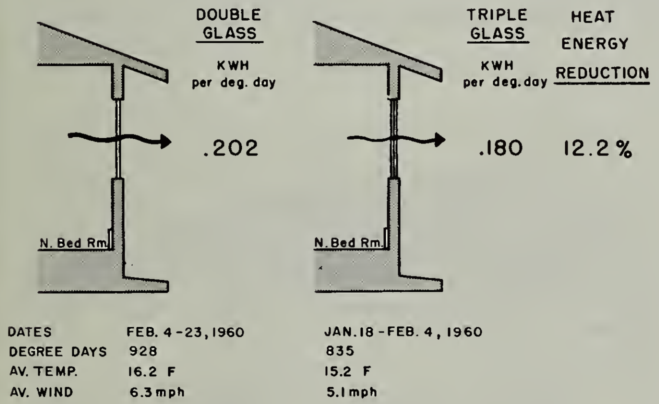

Figure 18.--Comparison of heat demands with double and triple windows.

Effect of Double and Triple Glazed Windows on Heat Energy.--A study made in January and February 1960 on heat requirements for a north bedroom showed (figure 18) a heat energy reduction from 0.202 to 0.180 kw.-hr. per degree-day--a reduction of 12.2 percent when the single north window had triple glazing as compared with double glazing. The two test periods involved were fairly uniform with respect to outside temperature, degree-days, and wind velocity. (The window area was 18.8 percent of the gross north wall area.)

Infiltration and Air Change.--The air infiltration studies showed that the number of air changes per hour increased, as expected, with an increase in wind velocity when the house was closed. However, the air change rates of 0.13 to 0.39 air changes per hour, as shown in figure 19, were much lower than the rates usually assumed in the design of heating systems. Yet, during actual living conditions when operating the shower room fan, range fan, and the clothes dryer, the added ventilation greatly overshadows the modest changes resulting from changes in wind velocity and outside temperatures. With both shower room and range fans operating, the air change rate increased to 1-1/3 per hour. It would appear that a practical design condition for a tightly constructed, well-insulated and weather-stripped house would permit an assumption of approximately 3/4 of an air change per hour as reasonable.

Relative Humidity Conditions.--The moisture conditions maintained in House A, occupied by the actual family during the winter of 1960-61, showed (Fig. 20) that in the first floor living areas the relative humidity varied from a low of 40 percent to a high of 60 percent in the fall when outdoor temperatures were fairly high.

During the first part of the winter, up to January 16, 1961, all windows were double glazed (except one north living room window was triple glazed). In zero degree and colder weather of this period, considerable condensation occurred on the double glazed windows but none on the triple glazed. When all windows were triple glazed, condensation was no problem except for a few times during subzero weather.

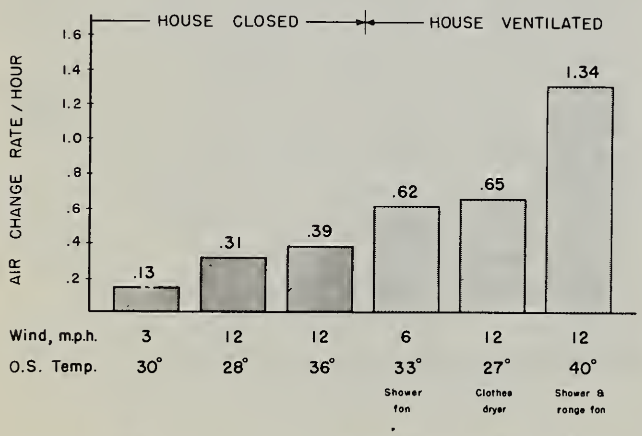

Figure 19.--Air change rates under different conditions.

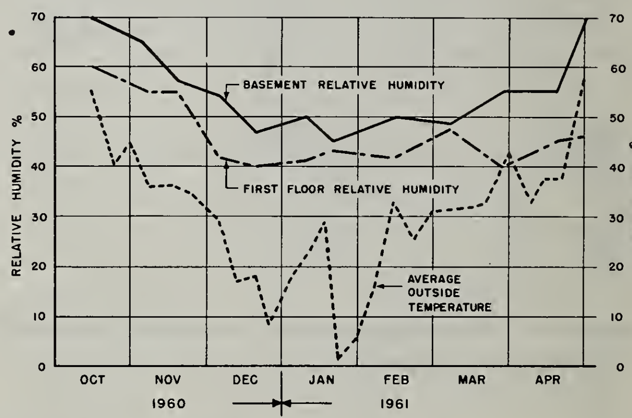

Figure 20.--Inside relative humidity in relation to outside temperatures.

Heat Loss from House A.--Procedures given in the ASHRAE Guide and Data Book were used to calculate the heat loss of House A. Infiltration loss was based on the standard one volume air change per hour and double glazing was assumed used. Of the total heat loss, shown in figure 21, only 1/3 occurs through the insulated ceiling, walls, and floors. Properly applied blanket insulation, quality weather-stripped windows, insulating sill sealer, large sheets of insulating sheathing extending from the foundation to the top of the wall all helped reduce infiltration in these research houses to an estimated 1/2 air change per hour. Attention to these and other quality construction details including use of triple glazing in cold climates will achieve a more balanced heat loss condition, reduce heating costs, and provide more comfortable living conditions.

Heat Supplied to House A.--A study was made of the total heat supplied to the first floor of House A during the period February 5 to 23, 1960, when outdoor temperatures ranged from -8°F. to 40°. Figure 22 shows that the baseboard heaters contributed approximately 75 percent; the actual and simulated appliances and lights, 11 percent; the assumed family, 5 percent; and solar radiation, 9 percent. The last three are items which are usually overlooked as heat sources although they contribute toward the heating of our homes regardless of the type of fuel used. These percentages will vary in different homes depending upon the amount of glass exposed to the sun, the number of occupants, and the appliances used; also they will vary at different times during the winter. In mild weather, such as the fall or spring, the internal heat loads and solar radiation may contribute a substantial share of the total heating requirement. In the two research houses, 14 percent of the gross south-wall area was in glass and at the time of this study, double glazing was being used.

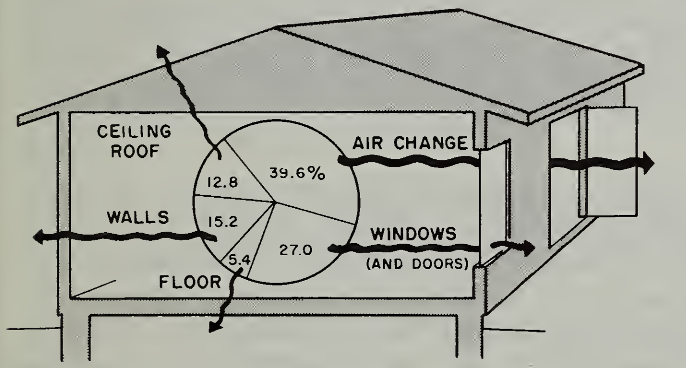

Figure 21.--Calculated heat losses from research house A.

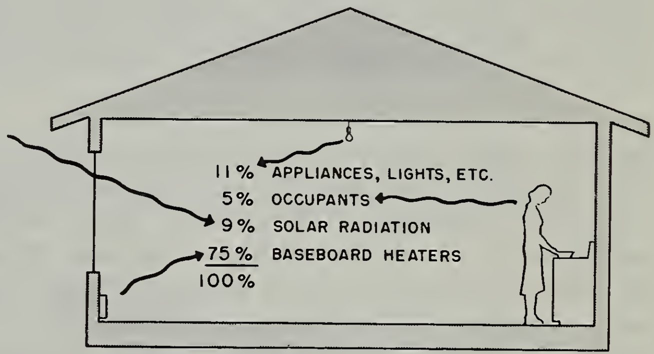

Figure 22.--Sources and amount of heat supplied to house A.

ACKNOWLEDGMENTS

Coauthors of this research house project report were D. B. Anderson, R. R. Leonard, and G. A. Erickson of Wood Conversion Co., and Dr. R. C. Jordan, Professor and Head of Mechanical Engineering Department of the University of Minnesota, who also served as technical consultant.

This study was sponsored by Wood Conversion Company which wishes to acknowledge the valuable assistance and cooperation of the Andersen Corp.; Minneapolis-Honeywell Regulator Company; Edwin L. Wiegand Co.; Northern States Power Co., all of whom have contributed liberally during the planning and executing of the work.

MOISTURE CONTROL IN HOUSES

by

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Moisture in various forms is often responsible for high maintenance costs involving paint failures, staining of siding, and even decay. They often are caused by moisture vapor condensing within walls during cold weather. Water vapor from within the house moves through the wall, condenses, and forms frost on the sheathing and on the back face of the siding. During mild weather, the moisture from the melting that occurs stains the face of the siding or causes the paint to blister and peel when it comes out on the underside of the paint film.

In the early 1930's and before, houses were not constructed so tightly as at the present time and condensation problems were rare. Modern houses are smaller, tighter, and contain more moisture-producing factors. Cold-weather condensation, consequently, is now often a major problem in houses. The use of insulation also is a contributing factor because of the consequent drop in heat losses. This causes parts of the house, such as the sheathing and siding, to remain colder than they do in uninsulated houses; and when water vapor moves through the walls, it condenses on these colder surfaces.

The Forest Products Laboratory receives hundreds of telephone calls and letters each year on moisture problems. Such problems and others caused by excessive moisture can usually be eliminated. The best time to eliminate or prevent these moisture problems, however, is before and during the time the house is being built. Ordinary precautions taken during construction will save many dollars in future maintenance costs.

1/ Maintained in cooperation with the University of Wisconsin.

Sources of Moisture

Generally there are three sources of moisture that must be considered in the application of control methods. These sources are (1) the inside of the house, (2) the soil under and around the house, and (3) the outside in the form of rain or snow.

Inside

Perhaps the most common and the most troublesome source is the moisture produced within the house. It is the major cause of condensation problems that results in peeling paint, moisture or frost on window surfaces, and stained plaster. This moisture can come from shower baths, washing and drying of clothes, cooking, ironing, plants, furnace humidifiers, and respiration of occupants.

It is estimated that moisture from household sources, not including furnace humidifiers and respiration of people, amounts to about 2 to 3 gallons of water each day. In many cases, this moisture in the form of vapor moves through the walls and ceiling, condensing on cold surfaces which are below the dew point temperature.

Ground

The second general source is ground moisture. This moisture can enter the house or be retained by framing members because of inadequate or poor construction. Ground moisture can enter crawl spaces and move by capillary action through unprotected concrete slabs or masonry walls. Control is important.

Outside

Problems attributed to moisture from outside sources are often caused by wind-driven rain that enters the wall by way of the siding joints. Moisture enters through breaks in the paint film at siding laps and butt joints. This usually causes the backs of the siding to become wet and is often responsible for staining or paint failures.

Another moisture source is from ice dams which can form at the cornice or roof overhang after heavy snows and cause water to enter wall and ceiling areas.

Control of Moisture

Interior

Excessive moisture produced within the house should be reduced when there are condensation conditions causing damage. The use of a vent fan during preparation of meals, the reduction or elimination of furnace humidifiers, the venting of clothes dryers, and the use of exhaust fans in the bathroom during showers are some of the practices that can be followed to reduce excessive moisture.

Perhaps the most important factor in the elimination of condensation problems is the installation of vapor barriers. Vapor barriers resist the movement of water vapor through walls and ceiling in cold weather. Most insulations, such as blanket or batt types, are provided with a vapor barrier; some are satisfactory, others have low resistance to the passage of vapor. Vapor barriers may consist of a kraft-backed aluminum foil, aluminum-coated paper, polyethylene films on paper, or asphalt-coated single or duplex papers. These barriers are rated on their "perm" value, which is a measure of vapor movement through a material, or "grains per square foot per hour per inch of mercury difference in vapor pressure." In other words, the lower this perm value, the better the barrier.

Perm values for some typical barrier materials are as follows:

	Perms
Paper-backed aluminum foil	0.003
4-mil polyethylene	.08
Paper laminated with asphalt	0.25 to 0.40

The type of barrier selected should take into account the type of exterior finish used. For example, the use of aluminum siding or other impervious exterior covering requires an excellent vapor barrier to insure little or no movement of vapor through the wall. The Federal Housing Administration has set down requirements for various conditions of use. These are based on the "U" value of the wall and on the composite permeance of the materials on the cold side.

To be most effective, vapor barriers are installed as close to the inside surface of exterior walls and ceilings as possible. The usual location is directly on the studs or underside of the ceiling joists. Barriers on insulation batts or blankets usually are made with a flange which should be placed over the edge of the studs. This results in a tight joint when the wall covering is applied. Areas around window and door openings are ordinarily not protected by barriers. It is good practice, however, to protect these areas with vapor barriers placed over framing members and carried to the edge of window and door jambs and sills.

Condensation problems are often caused by using blown-in insulation in older houses where the application of a vapor barrier is a problem. In such instances, it is advisable to provide some resistance to the movement of vapor in the type of paint used on the inside exposed surfaces. For example, an aluminum primer followed by an oil base or other type of finish paint or a pigmented primer-sealer and finish coat will provide a reasonably good vapor-resistant coating. Two coats of the primer will increase this resistance.

Ground Moisture

Control of ground moisture is easily accomplished in houses with a crawl space. Roll roofing, 4-mil polyethylene, or some other vapor barrier placed over the soil will insure that moisture content of framing members will not be excessive. A maximum value of 1 perm is required by the Federal Housing Administration for materials used in this manner.

Vapor barriers placed under concrete slabs and properly lapped at the joints will prevent movement of moisture through the slab. These barriers are placed before the concrete is poured. The material used for the barrier should have some resistance to bacteria, abrasion, and other hazards. The Federal Housing Administration requires a maximum of 1/2 perm for water-vapor barriers used under concrete slabs.

A series of procedures have been developed at the Laboratory to determine the adequacy of vapor barriers used under concrete slabs and in crawl spaces. They include the determination of resistance to deterioration from alternate wetting and drying and from soaking; wet tensile strength; resistance to decay; and other strength and temperature evaluations.

Typical vapor barriers were exposed to these conditions for the purpose of improving the procedures as well as improving the barriers. At the present time, the American Society for Testing Materials has a tentative set of test methods that have been developed from these exploratory procedures (ASTM Designation E 154).

Exterior

Problems from the third source of moisture, rain or melting snow, can be eliminated or greatly reduced. Capillary movement of moisture that enters at the lap or butt joints of the siding is reduced by using a water-repellent treatment. Many manufacturers market their siding with treatment of this type. As additional coats of paint are applied to a house, the lap joints receive increased protection, and entry of water in this manner is usually reduced.

A current study at the Forest Products Laboratory involving the use of a water-repellent dip treatment for drop siding has indicated that this treatment practically eliminates capillary movement of moisture. The back face of treated drop siding in a unit under study for 3 years has been free of moisture.

Ice dams are not problems in most areas of the United States, but they often cause damage in northern climates. They result when heavy snows form a thick blanket on roof slopes and heat loss from the occupied rooms allows the snow to melt because of poor attic insulation. When outside temperatures are low, ice dams are formed at the cold area of the cornice. The melted snow then backs up and enters at the facia or shingle area into the ceiling and walls. Remedies consist of good attic insulation to reduce heat loss and good ventilation to insure attic temperatures that are comparable to outside temperatures. The use of a wide flashing of light roll roofing placed under the shingles during construction will help to prevent water entry.

Relative Humidities

Relative humidities within homes vary a great deal, depending on living habits of the occupants and moisture-producing equipment within the home. Houses adequately protected with vapor barriers can generally be safely maintained at 40 percent relative humidity when outdoor temperatures are 0° to -20°F. In houses without vapor barriers, however, the relative humidity should be 25

percent or less under the same outdoor temperature conditions. The relative humidity is usually too high when condensed moisture forms on the inside surface of window glass protected by a storm window. For example, at an outside temperature of $0^{o}F.$ and an inside temperature of $70^{o}F.$, condensation occurs on the inside of a storm-protected window glass at a relative humidity of about 42 percent. Without the storm window, condensation in the form of frost will occur at a relative humidity of about 22 percent.

Ventilation

Another important factor in moisture control is attic ventilation. Good attic ventilation will aid in preventing the collection of excessive moisture. The amount and location of this ventilation is important. Ventilation studies made by the Forest Products Laboratory have indicated that inlet as well as outlet ventilators provide a more positive movement of air than outlet ventilators alone. With ventilators located only at the ridge areas of a gable house, the amount and direction of the wind is a major factor in the movement of air through the attic. Inlet ventilators located in the soffit area under the roof overhang and outlet ventilators located near the ridge produce a "stack" effect and insure the removal of excessive moisture. This movement is not dependent on the wind.

It is generally good practice to distribute both inlet and outlet vents to prevent any pockets of dead air spaces. The use of continuous inlet vent slots located behind the facia board of the cornice has proven successful. Gable end or ridge outlet ventilators are located as high on the roof or ridge area as is practical.

The minimum recommended net areas usually vary by the type of roof. For example, a gable-roofed house with vents only at the gable ends should have a total minimum net area of 1/300 of the ceiling area. The same type of house with both inlet and outlet ventilators should have the net area of each type equal to not less than 1/900 of the ceiling area.

Another dividend resulting from good attic ventilation is the elimination of damage of ice dams. As noted previously, the use of inlet and outlet ventilators will insure a cooler attic because of the resulting air changes. Thus, damage caused by melted snow or by water vapor from within the house will be eliminated or reduced materially.

PAINT AS A VAPOR BARRIER

by

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It is well established that early blistering and peeling of exterior house paint will occur when moisture accumulates in the side walls of a dwelling faster than it can be dissipated through cracks and other forms of ventilation, or by migration through the outside coat of paint. In other words, it is essential that the permeability of the vapor barrier on the warm side of the wall be lower than the permeability of the exterior paint coating if the accumulation of moisture is to be avoided.

The problem is rendered more acute when the side walls are insulated, since insulation serves to reduce air circulation in the walls, and also insulation of the side walls is usually accompanied by weather-stripping and other operations which reduce the opportunities for moisture to escape from the dwelling.

A vapor barrier is most effective if it is built into the side wall on the warm side of the insulation. Sheets of metal foil or impermeable plastic are very effective for this purpose, and under favorable conditions do an excellent job. However, any vapor barrier, to be effective, must be continuous since even a small gap will allow moisture vapor to enter the wall and establish moisture conditions which can easily result in the peeling of exterior paint coats. Therefore, if the built-in vapor barrier is broken or if it was not installed at the time the building was erected, other means must be used. One of the most effective of these is the application of suitable paint coatings to the interior walls.

There are a number of types of paint available for the purpose and it is hardly practicable to test them all in actual houses, so it seemed desirable to determine whether available laboratory methods would be adequate to predict the behavior of various paint systems as vapor barriers.

This laboratory has developed a method of determining the permeability of painted surfaces which is described in Scientific Section Circular 785, by Felicione, Garlock and Rowland, issued in December 1959. Briefly, the method places a piece of gypsum board to which the paint system has been applied over a pan containing calcium chloride, sealing the edges carefully so that all moisture reaching the calcium chloride must pass through the paint film. The assembly is weighed daily until the gain in weight is constant. At that time, the permeance is calculated by a formula given in the paper. The American Society of Heating and Air-Conditioning Engineers has established a permeance of 1 perm, as the maximum for a satisfactory interior vapor barrier. The equipment used in this test is illustrated in

Figure 1, and the results of several paints used as one- and two-coat systems are given in Table 1.

Figure 1.--Vapor barrier test pan.

Table 1.--Permeance, in perms

Paint	One Coat	Two Coats
Emulsion I	3.25	0.65
Emulsion II	4.87	1.41
Emulsion III	15.02	4.85
Aluminum Paint	8.95	1.06
Alkyd Flat	2.52	1.01
Alkyd Semi-Gloss	1.04	.69

In order to check the performance of these paint systems, a "Blister Box" was used. This device is described in Scientific Section Circular 780, by Garlock and Rowland.

The warm chamber is maintained at 85° F., and 85% relative humidity, while the cold side is maintained at 32°-34° F., during the day and allowed to regain ambient temperature during the night. Various paints, as vapor barriers, were tested by painting them on the warm side of an assembly simulating a wall, with a conventi nal exterior house paint system on the cold side. Results are given in Table 2.

Table 2.--Exterior blistering with different interior paint systems.

Permeance of interior system	Area blistered in two weeks	Permeance of interior system	Area blistered in two weeks
0.65	0	4.87	10
1.01	0	8.95	15
1.41	0	15.02	25
3.25	10	34.64 uncoated board	75

Since these results are reported after two weeks exposure, and it may be assumed that blistering would become more severe with the passage of time, the maximum of 1 perm would seem to be reasonable.

Discussion: From the data reported above and from numerous other observations made over the years, several conclusions may be drawn. First, an adequate number of coats of paint can make an effective vapor barrier. The effectiveness of paint as a vapor barrier is determined (1) by the completeness with which the wall is covered--that is, all areas including areas which are difficult to access, such as walls behind radiators, the interiors of cupboards and similar places, must be painted; (2) by the integrity of the total film--that is, it must be free from thin places, gaps, and holidays; (3) by the ratio of pigment to vehicle, since a paint with a high proportion of pigment will not have enough vehicle to form a continuous film and will, therefore, be permeable as shown by Emulsion III in Table 1; and (4) by the type of vehicle--the evidence being that this is of the least importance.

The importance of a continuous film is shown by the great improvement of two coats over one. In every case except the semi-gloss enamel, the reduction in permeance is much greater than would be expected by doubling the thickness of the film. This indicates that the second coat covers thin spots and gaps left in the first coat. In this connection, it should be remembered that the panels used in these tests were prepared in the laboratory by competent technicians. Even greater spreads would be expected in field applications on walls of rooms, where surface irregularities and other problems would prevent the application of uniform films.

Conclusion: A continuous film of paint on the interior wall of a dwelling will furnish an adequate vapor barrier so that the passage of moisture will be reduced to the point that exterior paint does not peal, if the following conditions are met:

(1) The film must be continuous, covering all areas of the wall. Obviously, cracks and holes must be sealed or calked.

(2) Sufficient paint is applied. The amount of paint necessary is largely determined by the ratio of pigment to vehicle. If this is low, as shown by a glossy or semi-gloss surface of the dried paint, less paint is required than if it is high, as shown by a flat surface. In any case, two coats of paint appear to be required.

(3) The nature of the vehicle, that is, oil, varnish, synthetic resins, or latex, appears to be much less important. Although there are differences, depending upon the vehicle used, these differences are not of the same order of magnitude as the differences between one and two coats, and between a continuous film and a film with pores or gaps.

FIELD MEASUREMENTS OF AIR INFILTRATION IN 10 ELECTRICALLY HEATED HOUSES

by

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INTRODUCTION

At the request of the Rural Electrification Administration, of the U. S. Department of Agriculture, field measurements were made of air infiltration in 10 electrically heated houses in the region served by the Indiana Statewide Rural Electric Cooperative, Inc. The study was made to assist the Rural Electrification Administration in correlating computed heating loads with observed use of electrical energy for heating.

In planning the study, one- and two-story brick and frame houses built over basements, crawl spaces, and concrete slabs on ground were considered to be representative of a majority of residential construction. Ten residences comprising 8 out of a possible 12 combinations of the above constructions were selected for the study.

DESCRIPTION OF HOUSES

A summary of the significant data on the types of constructions, materials, and dimensions of the 10 residences investigated is shown in Table 1. Of these residences four were of brick veneer, five frame, and one of stone veneer. Six of these were one story and four were two stories high. Five buildings had basements, three had crawl spaces, one had a combination of basement and crawl space, and the one apartment was built on a concrete slab on ground. The apartment was an end unit, with three walls exposed to the weather, of a one-story building of brick veneer and frame construction. There were five practically new houses, and the age of the others ranged from 20 to 46 years, averaging 31 years.

The floor area of the heated space in the buildings ranged from 598 square feet to 1,922 square feet, with an average of 1,370 square feet. The heated volume of the residences averaged 10,820 cubic feet. The ceiling heights of the houses ranged from 7'6" to 9'4" for the first floor and from 6'6" to 8'0" for the second floor in the four 2-story houses. Insulation was used in the walls and ceilings of all houses and in the floors of seven. Sheathing paper or a vapor barrier was used in all houses. Four of the five new houses and one 20-year-old house employed vapor barriers. Plaster or plasterboard was used as the interior finish for the ceiling and walls in all houses.

The total lengths of door and window cracks for each house are also shown in Table 1. The computations were made from dimensions taken from the original floor plans for each house. The crack lengths for doors and single-hung windows were taken as the perimeter length of the opening whereas that for a double-hung window was taken as the sum of the perimeter length and the meeting rail length. Neither sealed windows nor sealed window sections were included in the computation of the crack lengths.

Table 1.--Dimensional and construction data of residences

House	Size of heated space		No. of stories	Wall 1/ materials	Foundation type	Age	Crack length	
	Floor area	Volume					Doors	Windows
	Sq. Ft.	Cu. Ft.				Yrs.	Ft.	Ft.
A	1,220	9,750	1	Brick veneer	Crawl space	20	57	219
B	1,229	9,830	1	Frame	Basement	30	38	280
C	1,510	12,080	1	Brick veneer	Crawl space & basement	New	38	90
D	1,230	9,520	2	Frame	Basement	20	38	279
E	1,510	12,950	2	Frame	Basement	40	57	252
F	1,658	13,240	1	Stone veneer	Basement	New	91	231
G	1,130	8,460	1	Frame	Crawl space	New	40	162
H	1,696	13,220	2	Frame	Crawl space	46	56	260
I	1,922	14,480	2	Brick veneer	Basement	New	39	176
J	598	4,680	Apt.	Brick veneer	Slab on ground	New	38	48

1/ All houses of brick or stone veneer construction employed 4" of masonry on the outside of 2"x4" frame and interior finish.

Air infiltration is defined as the air leakage of a building through cracks and interstices around doors and windows and through the floor, walls, and ceiling that cannot be directly controlled by the occupants. Ventilation comprises the controlled displacement of air in a building through openings, such as windows, doors, ventilators, and combustion heating devices, by either natural or mechanical forces. The magnitude of the air infiltration depends on the wind and temperature forces acting on the building, its height and exposure, the type of materials used, workmanship, and the condition of the building.

The air change rate of an enclosure is defined as the hourly volumetric rate at which air enters (or leaves) the enclosure divided by the volume of the enclosure.

The infiltration of air in each of the 10 electrically heated residences was determined by a tracer gas technique.[1/] By this technique, the rate at which fresh air enters a house is determined by introducing a small amount of a tracer material into the space and measuring the rate of change in concentration of the tracer material by means of one of its physical properties. The apparatus used was the portable infiltration meter developed at the National Bureau of Standards, consisting of a measuring and control console and ten sensing devices as shown in Figure 1.[2/]

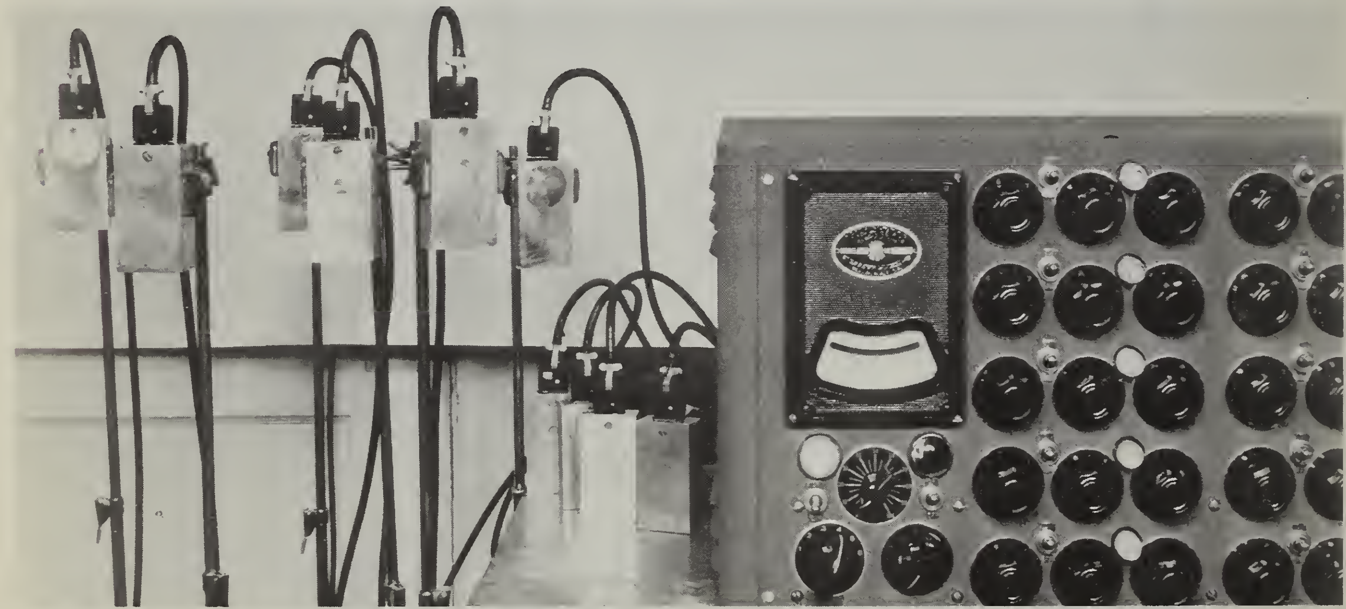

Figure 1.--Control console and sensing elements of portable helium infiltration meter.

1/ Marley, W. G. The Measurement of the Rate of Air Change. Journal of the Institution of Heating and Ventilating Engineers, V. 2, pp. 499-503. 1935.

2/ Coblentz, C. W., and Achenbach, P. R. Design and Performance of a Portable Infiltration Meter. American Society of Heating and Air Conditioning Engineers Transactions, V. 63, pp. 477-482. 1957.

Approximately 1/2 percent of helium in relation to the total volume of the house was introduced after the test apparatus had been brought to temperature equilibrium with the air in the house. The helium was introduced into each room and was mixed with the room air by using several desk fans. The outside doors and windows were closed, whereas closets and cupboards, and all doors inside the living area were kept open during the test, so the concentration of tracer gas would decay in all of these spaces at about the same rate. The 10 sensing probes were placed near the centers of the rooms about 3 feet above floor level, and readings were taken at each station at 5-minute intervals for a period of 1 hour or more. During a test, the indoor and outdoor temperatures were measured, and the wind velocity and direction were observed in the vicinity of the house about 10 feet above ground. Two to four such infiltration tests were made in each dwelling at prevailing conditions over a period of about 2 days.

TEST RESULTS

A total of 30 infiltration tests was made in the 10 houses. The data from two of these were discarded, however, because significant changes in the infiltration rates occurred during the test period, as a result of opening the outside doors.

It can be shown [3] that the air change rate in a single enclosed space during a selected interval is directly proportional to the natural logarithm of the ratio of the concentrations of the tracer gas at the beginning and end of the time interval, if the forces causing infiltration remain constant. Under these conditions, a constant infiltration rate would be represented by a straight line on semilogarithmic graph paper. Thus, a practical way to determine the average infiltration rate from a series of measurements of tracer gas concentration in a given room is to plot the data on semilogarithmic graph paper.

The change in relative concentration of the tracer gas with time at each station of observation during the 28 tests made in the 10 sample houses was plotted on semilogarithmic graph paper to obtain an average air change rate, and to reveal the steadiness of the infiltration process. Two such graphs are shown as Figures 2 and 3 to illustrate the results in a two-story and a one-story house, respectively. Figures 4 and 5 show the floor plans of the houses from which the infiltration data in Figures 2 and 3, respectively, were obtained. In Figures 2 and 3, the change in relative helium concentration with time for each room of the house is shown for a period of about 1 hour, together with the identification of the house and each room of the house. The concentration curves are plotted in groups of three on a repetitive scale so each curve can be more readily delineated. In most instances, a straight line was a good representation of the decay curve. In the few cases where a straight line was not a good approximation, the data for these stations were not used in determining the average value for the house.

3/ See footnote 2.

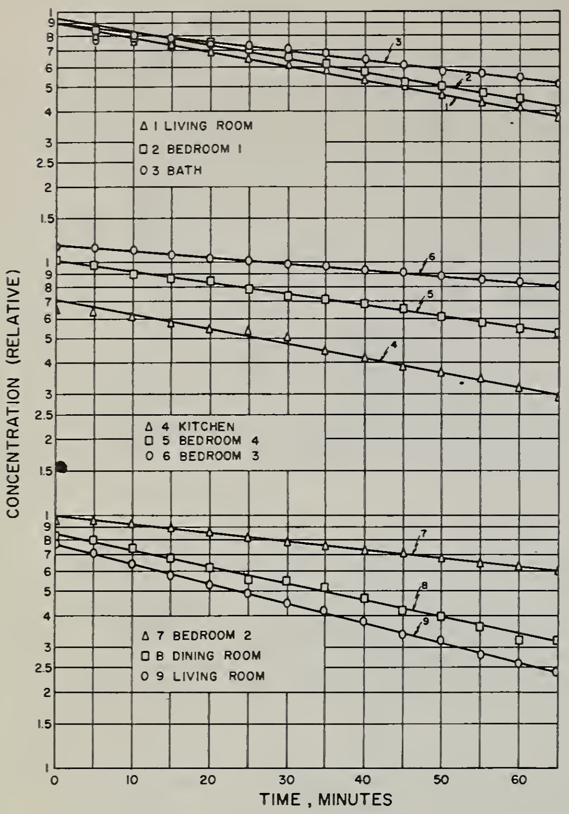

Figure 2.--Observed helium decay in the individual rooms of house H, a 2-story frame structure with a crawl space.

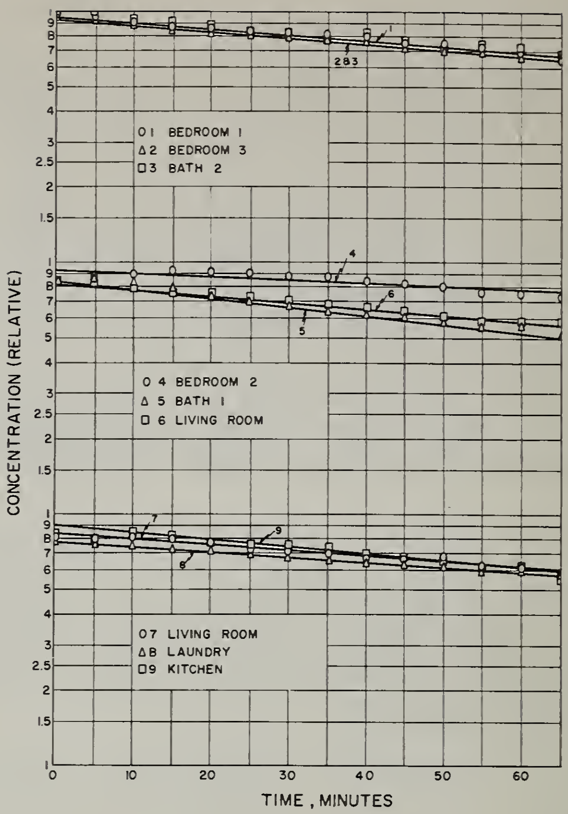

Figure 3.--Observed helium decay in the individual rooms of house C, a 1-story brick veneer structure with combination basement and crawl space.

A summary of the room-by-room infiltration data is shown in Table 2. The air change rate for each room was computed as the natural logarithm of the ratio of the concentrations at the times 0 and 60 minutes taken from Figures 2 and 3. When more than one sensing device was located in a given room, the air change rate was taken to be the average of the computed values for all the stations in that room. The air change rate for the entire house was computed as the sum of the products of the air change rates in the individual rooms and the corresponding percentage of the total house volume represented by each room. In cases where the helium concentration data for a particular room were not usable, the volume of that room was not included in the total house volume. This procedure is tantamount to assuming that the infiltration rate of any space for which the data were not available or could not be used was equal to the average infiltration rate for the rest of the house.

Table 2.--Summary of room by room infiltration data in 2 houses

Name of room	Volume of room	Part of house volume	Air change rate related to-- Room	Whole house
	Cu. Ft.	Pct.	Air Changes Per Hour	
		RESIDENCE C		
Living room	2,704	25.0	0.35	0.088
Kitchen	2,448	22.7	.40	.091
Laundry	280	2.6	.30	.008
Bedroom 1	1,768	16.4	.32	.052
Bedroom 2	1,224	11.3	.21	.024
Bedroom 3	1,016	9.4	.32	.030
Bath 1	848	7.9	.48	.038
Bath 2	512	4.7	.32	.015
Total	10,800	100.0		0.346
		RESIDENCE H		
Living room	2,182	15.1	0.93	0.141
Dining room	2,182	15.1	.89	.134
Kitchen	2,433	16.9	.79	.132
Bedroom 1	1,847	12.8	.74	.095
Bedroom 2	1,794	12.4	.45	.056
Bedroom 3	1,794	12.4	.33	.041
Bedroom 4	1,674	11.6	.62	.072
Bath	522	3.6	.51	.018
Total	14,428	99.9		0.689

Table 3 is a summary of the average observed infiltration rate expressed in air changes per hour for each test and shows the average wind velocity and prevailing direction, the inside-outside temperature difference, and an air change rate adjusted to a 10 m.p.h. wind velocity and an indoor-outdoor temperature difference of 40° F. The average wind velocities that prevailed during the air infiltration tests ranged from 6 to 15 m.p.h., and the inside-outside temperature differences were between 20 and 64° F. The variation in outdoor conditions made it impossible to compare the observed air change rates of the 10 houses directly. Not enough tests were made with any of the houses to evaluate exactly the effects of wind velocity and temperature difference on the infiltration rate. However, a method for approximate adjustment of the observed values of infiltration rate for each building to a selected average climatic condition was used, as described in the following section.

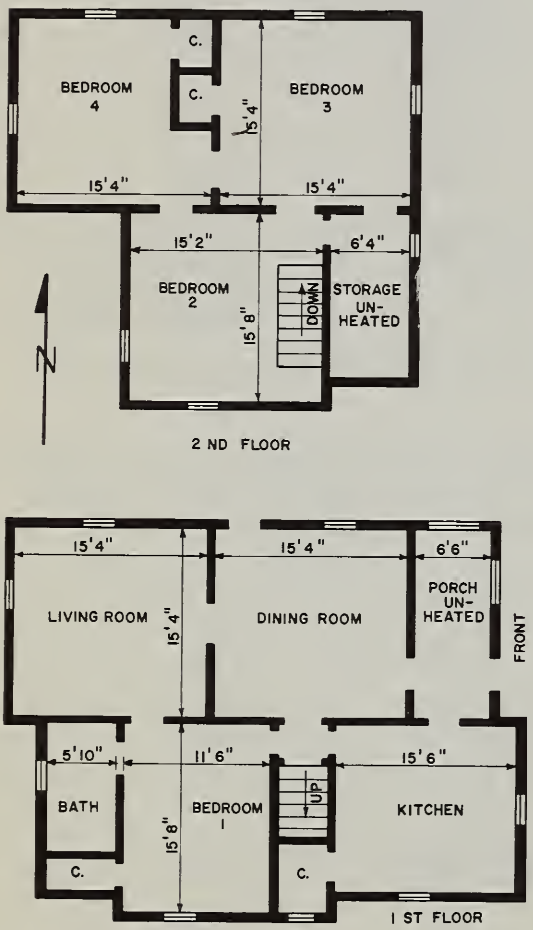

Figure 4.--Floor plan of house H, a 2-story frame structure with a crawl space, 46 years old.

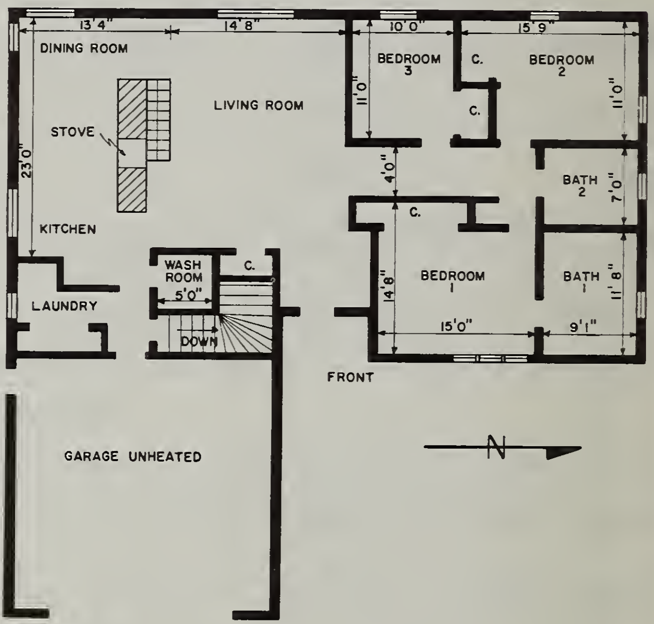

Figure 5.--Floor plan of house C, a new 1-story brick veneer structure with a combination basement and crawl space.

Table 3.--Summary of test results

House	Test No.	Observed wind conditions: Velocity	Observed wind conditions: Direction	Indoor-outdoor temp. diff.	Infiltration rate: Observed	Infiltration rate: Adjusted 1/ Each test	Infiltration rate: Adjusted 1/ Average
		Mph.		° F.	Air changes per hour		
A	1	15	SW	45	2/ 0.84	0.71	0.62
	2	15	W	45	2/ .77	.65	
	3	15	WNW	48	2/ .77	.63	
	4	15	W	46	3/ .58	.48	
B	5	6	N	42	.71	.78	.75
	6	6	N	43	.56	.61	
	7	11	S	43	.91	.86	
C	8	11	SW	27	.51	.57	.48
	9	15	SW	23	.42	.44	
	10	10	SSW	23	.35	.43	
D	11	13	SSW	24.5	1.14	1.24	.99
	12	12	SSW	20	.84	.99	
	13	10	SW	29	.67	.76	
E	14	11	W	41	.99	.95	.86
	15	10	W	41.5	.81	.80	
	16	6	NW	44	.76	.81	
	17	11	N	45.5	.94	.87	
F	18	6	WSW	54.5	.55	.53	.37
	19	12	WSW	49.5	.39	.34	
	20	8	WSW	46	.23	.23	
G	21	6	NW	48	.57	.58	.50
	22	6	SW	50	.42	.42	
H	23	6	NE-SW	38	.74	.85	.71
	24	6	SW	42.5	.60	.65	
	25	8	NW	53	.69	.64	
I	27	11	W	46	.52	.48	.48
J	28	6	NE	42.5	.58	.63	.66
	30	8	W	63.5	.81	.68	

1/ Adjusted to uniform indoor-outdoor temperature difference of 40° F., uniform wind velocity 10 mph.

2/ Open exhaust vents in kitchen and bathroom.

3/ Closed exhaust vents in kitchen and bathroom.

Published information 4/ on infiltration measurements in two test houses at the University of Illinois, one a two-story brick veneer structure over a basement and the other a one-story frame structure over a basement, indicated that the air change rate in each was directly proportional to the indoor-outdoor temperature difference and also to the wind velocity. The observed infiltration rates with no wind and no indoor-outdoor temperature difference were about 0.12 to 0.18 air change per hour in the two houses. The University of Illinois data further showed that an increase in wind velocity of 1 m.p.h. was equivalent to an increase in indoor-outdoor temperature difference of 2 to 4° F. in its effect on the infiltration rate. Thus, an expression of the form of equation (1) can be used to approximate the effect of wind and temperature difference on the air change rate for these test houses.

$$I = A + BW + CT \tag{1}$$

where

I = hourly air change rate.
W = wind velocity, m.p.h.
T = inside-outside temperature difference, ° F.
A = the air change rate with no wind and no temperature difference per hour.
B,C = the increase in the air change rate per unit increase in wind velocity and temperature difference, respectively.

Based on average values observed in the two test houses investigated by the University of Illinois, equation (1) would become:

$$I = 0.15 + 0.013W + 0.005T \tag{2}$$

A wind velocity of 10 m.p.h. and a temperature difference of 40° F. approximated the averages of the observed outdoor conditions during the tests of the 10 houses in Indiana. If it is assumed that the proportional change in air infiltration of these houses was similar to those reported by Bahnfleth for the two University of Illinois houses, equation (2) can be used to adjust the observed data from this investigation to the above-cited average wind velocity and temperature difference by the following relationship:

$$I_1 = \frac{0.15 + (0.013 \times 10) + (0.005 \times 40)}{0.15 + 0.013W + 0.005T} \times I \tag{3}$$

where I, W, and T are the observed values of air change rate, wind velocity, and temperature difference for any test and I_1 is the air change rate adjusted to a wind velocity of 10 m.p.h. and a temperature difference of 40° F.

4/ Bahnfleth, D. R., et al. Measurement of Infiltration into Residences, American Society of Heating and Air Conditioning Engineers Transactions, Vol. 63, pp. 439-452. 1957.
Ibid, Part II, pp. 453-476.

Table 3 shows the adjusted value of air change rate for each test and each house based on equation (3). These adjusted values should be considered as approximate values because the absolute and relative values of the constants A, B, and C in equation (1) probably differed from house to house. However, the adjusted values are probably more nearly comparable with each other than the measured values. The measured air infiltration rates of the two test houses [5] at the University of Illinois for these same wind and temperature conditions were 0.38 air change per hour for the two-story brick veneer house over a basement, and 0.55 air change per hour for a single-story frame house over a basement, equal in each case to about three times the air change rate with no wind and no temperature difference.

It will be noted in Table 3 that three tests were made of house A with kitchen and bathroom vents open, resulting in an average air change rate of 0.79 per hour, and one test was made with these vents closed with a corresponding air change rate of 0.58 per hour at nearly the same outdoor conditions. Since the volume of this house was 9,750 cubic feet, it appears that these two vents caused a combined ventilation of about 2,050 cubic feet per hour under the prevailing weather conditions.

Table 4 summarizes the adjusted air change rates in relation to the type of wall material and foundation, building height, and age of the building in the order of ascending values of air change rate. It indicates that the infiltration rate ranged from 0.37 to 0.99 air changes per hour under the same conditions.

Since only one house in each category was tested, with the exception of two 2-story frame buildings, care should be exercised in drawing conclusions about categorical differences in airtightness of the different types of houses. However, Table 4 shows that the air change rate of four of the new buildings was significantly lower than that of the older buildings. Although a general increase in air leakage might be anticipated as a house grows older because of deterioration of materials, it will be noted that one 20-year-old residence was among the five houses with the lowest air change rates. The new buildings were designed and constructed for electric heating systems, so it seems likely that efforts were made to keep the infiltration heat losses at a low level. A part of the windows in each of the new houses had fixed sections in them, and in house A, 20 years old, the windows in the living room had fixed sash and all of the window frames were caulked into the masonry.

Considering the three house characteristics, other than age, listed in Table 4, it will be noted that the four houses with the highest air change rates were all of frame construction and three of the four were two stories in height. However, these same four houses were 20 to 46 years old, so it is impossible to judge whether age, height, or material of construction was the more significant with respect to the rate of air exchange by infiltration.

5/ See footnote 4.

Table 4.--Adjusted [1] air change rate in relation to construction features of houses

House	Air changes per hour	Age of building	Number of stories	Wall material	Type of foundation
F	0.37	New	1	Stone veneer	Basement
C	.48	New	1	Brick veneer	Crawl space & basement
I	.48	New	2	Brick veneer	Basement
G	.50	New	1	Frame	Crawl space
A	.62	20 years	1	Brick veneer	Crawl space
J	.66	New	Apartment	Brick veneer	Slab on ground
H	.71	46 years	2	Frame	Crawl space
B	.75	30 years	1	Frame	Basement
E	.86	40 years	2	Frame	Basement
D	.99	20 years	2	Frame	Basement

1/ Adjusted to 10 m.p.h. wind velocity and 40° F. temperature difference.

AIR INFILTRATION BASED ON WINDOW AND DOOR CRACK LENGTHS

The air infiltration per unit crack length was calculated for the 10 residences at the selected condition of 10 m.p.h. wind velocity and 40° F. inside-outside temperature difference. Only doors and openable windows were used in computing the crack lengths. The air infiltration rate through the cracks was calculated by the following formula:

$$L = \frac{V \times I}{C} \tag{4}$$

where

L = air infiltration rate, cu. ft. per hr. (per foot of crack length).
V = volume of heated space, cu. ft.
I = observed air change rate (per hour) adjusted to 10 m.p.h. wind, 40° F. temperature difference.
C = total crack length, ft.

The sample houses are listed in Table 5 in the order of increasing values of unit air infiltration rate per foot of crack length of doors and openable windows. The unit air infiltration rate ranged from 15 to 45 cu. ft./hr. per foot to crack length for the selected conditions of 10 m.p.h. wind and an indoor-outdoor temperature difference of 40° F. The lower end of the range of values based on observed data is comparable with values published in the ASHRAE Guide [6] for weatherstripped double-hung metal or wood-sash windows, at the same wind velocity, whereas the upper end of the range of these values is comparable with the published value for a non-weatherstripped double-hung metal window and higher than the published value for a residential casement window with 1/32 in. cracks, at the same wind velocity. These comparisons are not entirely valid because the data published in the ASHRAE Guide do not take into account the effect of temperature difference on air infiltration.

An examination of Table 5 does not indicate any significant correlation between the unit air infiltration rate and age of the house or type of wall or foundation construction, but does show that the four 2-story buildings had a higher unit infiltration rate than four of the 1-story buildings and equal or lower infiltration rate than the 1-story houses J and C. However, the data on door and window crack lengths in Table 1 indicate that the door cracks constituted a higher percentage of the total crack length in houses J and C than for the other houses. This fact may account for the high unit air infiltration rate of these two 1-story houses since the cracks around doors are usually greater in width than those around windows. Residence C had the highest unit air infiltration rate and also the highest value of building volume per unit crack length, as shown in Table 5. This house had a large volume, but only a very few openable windows, which accounts for the high ratio of building volume to crack length. However, it does not account for the high value of unit air infiltration rate.

6/ American Society of Heating, Refrigerating, and Air-Conditioning Engineers Guide and Data Book, Fundamentals and Equipment, pp. 425. 1961.

Table 5.--Relation of air infiltration rate to crack length

House	Unit air infiltration rate	Adjusted air change rate	Building volume per unit crack length	No. of stories	Age of building	Foundation type	Wall material
	Cu. Ft. Per Hr. Per Ft. of Crack	Per Hour	Cu. Ft. Per Ft.		Years		
F	15	0.37	41	1	New	Basement	Stone veneer
G	21	.50	42	1	New	Crawl space	Frame
A	22	.62	35	1	20	Crawl space	Brick veneer
B	23	.75	31	1	30	Basement	Frame
D	30	.99	30	2	20	Basement	Frame
H	30	.71	42	2	46	Crawl space	Frame
I	32	.48	67	2	New	Basement	Brick veneer
E	36	.86	42	2	40	Basement	Frame
J	36	.66	54	1	New	Slab on ground	Brick veneer
C	45	.48	94	1	New	Crawl space & basement	Brick veneer

It should be noted that in these comparisons the infiltration through all avenues of leakage in the test houses is compared with the air leakage for windows only, as published in the ASHRAE Guide. The field study did not include measurement of the crack width of the windows and doors nor the identification of other sources of leakage such as fireplaces, chimneys, interstices in the wall construction, and penetrations by electrical and plumbing fixtures. Some of these factors may have contributed to the high value of unit air infiltration rate observed for house C.

INFILTRATION BASED ON AIR CHANGE RATE

The procedures described in the ASHRAE Guide 7/ for computing air infiltration rates by the air change method were applied to the 10 houses tested. Following the usual assumption that the total infiltration volume for a residence is equal to the sum of the infiltration volumes for the individual rooms, the computed air changes per hour by this method ranged from about 0.6 to 1.5. When the observed air change rates in the 10 houses were adjusted to the design weather conditions in Indiana by means of equation (3), the resulting infiltration rates ranged from about 0.54 to 1.45 air changes per hour, and are in good agreement with the computed values. However, comparisons on a house-by-house basis between observed air change rates, after adjustment by equation (3), and the values computed by the Guide procedures revealed numerous inconsistencies. Thus, the reader is cautioned against drawing more detailed conclusions from the data than are warranted.

7/ See footnote 6.

RESIDENTIAL HEATING AND COOLING LOADS

by

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Calculation procedures and information on building materials make it possible to calculate heating and cooling loads for almost any conceivable residential structure. As the arts of calculation of heating and cooling loads have progressed, the importance of adequate insulation and other thermal protection of the house have become more evident. The purpose of this paper is to present some results of comprehensive investigations of residential heating and cooling systems and to show the value of adequate insulation through comparison of measured and calculated loads.

HEATING

The heat losses of a residential structure are classified as transmission losses and those due to infiltration of outdoor air. Thermal conductivity values of building materials have been determined (1)[1/] quite precisely from guarded hot plate tests. Although the overall coefficient of heat transfer, U (Btuh per sq ft F deg), of a composite wall may also be determined by the guarded hot box method, which is similar, it is usually calculated from the known values of thermal conductance of the individual components substituted in the equation:

$$U = \frac{1}{R_t} = \frac{1}{\frac{1}{f_i} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{1}{f_o}} \qquad (\underline{1})$$

where f_i and f_o represent, respectively, the surface coefficients of the inside and outside air films; x_1 and x_2 are thicknesses of the materials; and k_1 and k_2 are thermal conductivities of the materials.

Heat losses due to infiltration of outdoor air may be determined from the equation:

$$Q = m\, c_p\, \Delta t \qquad (\underline{2})$$

where

Q = heat loss, Btuh

m = mass of infiltration air, lb/hr

c_p = specific heat of air, Btu/lb F deg

Δt = temperature difference between indoor and outdoor air, F deg.

1/ Underlined numbers in parentheses refer to references at end of this section.

In determining heat loss due to infiltration some uncertainties arise in the estimation of the quantity of air infiltrating per unit time. Factors (1) have been established for many types of windows and in recent years infiltration meters (2) have been developed to measure air change rates of buildings. The results of such measurements (3) have shown reasonable agreement between calculated and measured infiltration rates. However, careless construction practices may increase infiltration rates to double or triple the calculated values.

Transmission Heat Losses

Six houses have been built on the University of Illinois campus over the past 37 years specifically for the investigation of residential heating and air conditioning. The National Warm Air Heating and Air Conditioning Association has sponsored research in four of the houses (Research Residences 1, 2, 3 and 4) and the Institute of Boiler and Radiator Manufacturers has sponsored research in two houses (I=B=R Research Home and the I=B=R Hydronic Research House). The trade associations have paid all of the costs of research, including salaries, and the information has been made available to the public through University of Illinois Engineering Experiment Station Bulletins. The houses were constructed and instrumented in such a way that it was possible to measure the effects of changes in thermal resistance on heat loss and fuel consumption.

Research Residence No. 1 originally had no insulation or storm windows. After operation in this manner (4) the Residence was operated next with storm windows, then without storm windows but with 5-5/8 in. thick insulation added to the exposed walls and ceiling and finally with both insulation and storm windows. Information on the window and wall surfaces is given in Table 1.

Equipping the uninsulated Residence with storm windows resulted in a measured seasonal fuel saving of approximately 20 percent which was about 0.81 of that estimated from the calculated heat losses. The addition of insulation without use of storm windows resulted in a seasonal fuel saving of approximately 30 percent which was about 0.78 of the estimated saving based on calculated heat losses. Storm windows plus insulation resulted in an average fuel saving of approximately 45 percent which was about 0.68 of the estimated reduction.

As the heat loss was reduced, the deviation of actual fuel savings from estimated fuel savings increased. This was attributed to the fact that any errors in heat loss factors, and particularly infiltration factors, became more important as the total heat loss was reduced.

Wall-Window Combinations

The reduction of heat loss through a ceiling resulting from the addition of insulation is directly proportional to the change in the heat transmission

Table 1.--Data on windows and wall surfaces, Research Residence No. 1

No.	Item	
1	Number of Window Openings	50
2	Number of Windows Equipped with Storm windows	48
3	Number of Door Openings to Outdoors	2
4	Number of Storm Doors	1
5	Area of Exposed Window Openings, Sq. Ft.	525
6	Area of Windows Equipped with Storm Windows, Sq. ft.	522
7	Area of Exposed Door, Sq. Ft.	24.5
8	Area of Double Door, Sq. Ft.	24.5
9	Gross Area of Exposed Structure, Sq. Ft.	3004.5
10	Net Area of Exposed Wall (Windows and Doors Excluded), Sq. Ft.	2455
11	Ratio of Storm Windows and doors to Total Exposed Openings, Percent	99.4
12	Ratio of Total Openings to Exposed Wall, Percent	18.3
13	Ratio of Total Exposed Openings to Net Wall, Percent	22.4

coefficient. However, a wall heat loss includes not only that through the wall section but also that through windows included in the wall. The combined U factors of the window and wall result in an average U value. As the percentage of window area increases, the effect of the wall insulation decreases as is shown in Fig. 1.

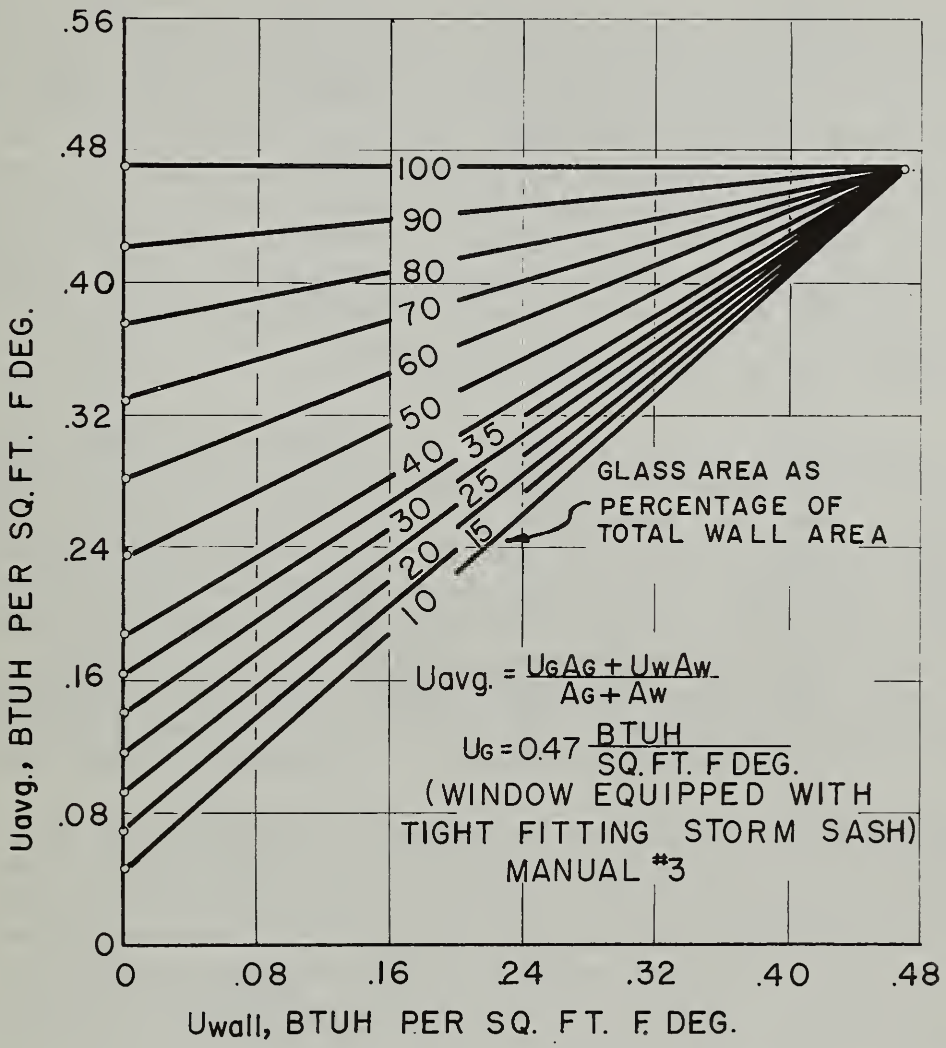

Fig. 1 Effect of glass area on thermal resistance of a wall.

For example, a wall with a U value of 0.24 Btuh per sq ft F deg that has a 10 percent window area (window equipped with storm sash) has an average U value of 0.26 Btuh per sq ft F deg. If insulation were added to the wall to reduce its U value to 0.08 the combined window-wall U value would then be 0.12 Btuh per sq ft F deg. This is one of the reasons that it is not advisable to merely specify certain insulation thicknesses for a given

heating application. It is better to specify the heat loss per sq ft of floor area that is required for the particular application. In remodeling existing structures it is sometimes not feasible to add insulation to the walls. The same overall effect of reducing heat loss per sq ft of floor area can be achieved by adding insulation to the ceilings and of course by adding storm sash if none were utilized previously.

Research Residence No. 4, a three-level frame and masonry structure, as originally constructed had no insulation on the concrete block walls in the crawl space and on the lower level, 2-in. glass fiber batt-type insulation in the frame walls of the middle and upper levels, and 4-in. glass fiber batt-type insulation in the ceilings of the middle and upper levels. As shown in Table 2 the total design heat loss was approximately 91,800 Btuh. (Design conditions for Urbana, Illinois, are 70° F. indoors, -10° F. outdoors, with a 15 mph wind). Some special studies were scheduled for the 1960-61 heating season and the heat loss was to be reduced to meet the requirements set forth in the "All Weather Comfort Standard for Electrically Heated and Air Conditioned Homes."

Urbana is in an area with a heating season of approximately 6000 degree days and the Standard recommends that the heat loss be limited to 32 Btuh per sq ft of floor area. To accomplish this, the interior faces of the lower level concrete block walls were furred out and provided with 3-in. thick glass fiber batt-type insulation. Expanded plastic board-type insulation of 2-in. thickness was applied to the crawl space walls. In addition, the glass fiber insulation was applied at the ends of the joist spaces in the crawl space and lower level. The walls of the middle and upper levels were not changed. The middle level ceiling insulation was increased to 6 in. and the upper level ceiling insulation to 7 in.

The comparison in Table 2 shows that the greatest reductions in heat loss were due to addition of insulation to the crawl space and lower level walls. The lower level heat loss was reduced by approximately 13,000 Btuh and the crawl space by approximately 5,000 Btuh. The middle and upper level heat loss reductions were not nearly as significant since the original insulation of those levels had been sufficient to maintain reasonable values of heat loss per sq ft of floor area. The calculated heat loss of the entire house was reduced by 27,000 Btuh.

Instrumentation in all of the houses has included equipment to accurately measure the fuel input to the heating unit as well as the total energy input to the entire house. The total energy input, adjusted for heating unit efficiency, is one means of measuring the heat loss of a structure for comparison with the calculated loss. Table 3 shows comparison of measured and calculated heat losses of Research Residence No. 4 for the 1959-60 and 1960-61 heating seasons.

The energy delivered to the furnace bonnet was determined from the fuel input to the furnace and the bonnet efficiency. The additional

Table 2.--Room heat losses and heat gains, University of Illinois, air conditioning Research Residence No. 4

Room	Heat Loss, Btuh*		Heat Gain, Btuh**	
	(1)	(2)	(1)	(2)
Family Room	17,974	12,401	5,957	4,000
Instrument Room	12,267	6,212	5,617	4,702
Bath	1,977	654	(3)	(3)
Lower Level Total	32,218	19,267	11,574	8,702
Entry	3,251	3,189	2,565	2,395
Living Room	7,480	5,819	6,900	6,810
Dining Room	7,089	6,446	2,868	2,795
Kitchen	5,574	4,704	2,813	2,704
Mid Level Total	22,494	20,158	15,146	14,704
S E Bed Room	6,756	5,079	5,040	4,225
S W Bed Room	5,537	4,209	4,125	3,945
N W Bed Room	4,727	3,615	2,899	2,815
N E Bed Room	4,802	3,807	2,855	2,785
N Bath	2,054	1,525	1,010	931
S Bath	1,639	1,457	640	535
Hall	(4)	586	(4)	(4)
Upper Level Total	25,518	20,278	16,569	15,236
Crawl Space	10,392	5,212	(5)	(5)
House Total	91,792	64,915	43,289	38,642

1/ No insulation on concrete block wall, 2-in. insulation in frame walls, 4-in. insulation in ceilings.

2/ With 6-in. insulation in Mid Level ceiling, 7-in. insulation in Upper Level ceiling, 3-in. insulation in Lower Level sidewalls, and with 2-in. insulation applied to Crawl Space Walls.

3/ Included with Family Room.

4/ Included with Bedrooms.

5/ No allowance for heat gain to Crawl Space.

* As determined from 1960 ASHRAE Guide.

** As determined from NWAHACA Manual No. 11, 1959 ed.

Table 3.--Comparison of measured and calculated heat losses, Research Residence No. 4

1959-60

	Measured Input (24 hour average) Btu/day	Btuh	Calculated Loss Btuh
Energy delivered to furnace bonnet	720,000	-	-
Additional energy input	240,000	-	-
Total energy (24 hour average indoor-outdoor temp. difference = 40° F.)	960,000	40,000	45,900

1960-61

Weather Conditions: Indoor-Outdoor Temp. Diff. °F.	Wind	Measured Input Btuh	Calculated Loss Btuh	Ratio = Measured Input / Calculated Loss
61	Calm	47,260	49,400	.96
64	10mph NE	47,780	51,670	.92
72	8mph N	57,175	58,200	.98

Note: Calculated heat losses at 80° F. indoor-outdoor temperature difference and 15 m.p.h. wind: 91,800 Btuh for 1959-60 and 64,900 Btuh for 1960-61.

energy was electrical energy required for lighting, cooking, and to drive the blower motor. The total energy input for a 40° F indoor-outdoor temperature difference was approximately 40,000 Btuh as compared with a calculated loss of 45,900 Btuh. The calculated loss was based on temperature difference only and no adjustment was made for average wind speed. Of course, the measured loss was dependent on the assumed efficiency of the furnace.

During part of the 1960-61 heating season a ducted central electric furnace was utilized in Residence No. 4. Since cooking, water heating and lighting were also done electrically, it was possible to determine exactly the energy input to the house. Energy input measurements were made on several occasions between the hours of 4 and 6 A. M. while steady outdoor and indoor conditions prevailed and the measurements were not affected by occupants or solar heat gains. The results of four of these studies are shown in the lower part of Table 3. The measured values in kw were converted to Btuh. The calculated loss was based on the design heat loss multiplied by the ratio of the actual to design indoor-outdoor temperature difference. The calculated values were not adjusted for wind speeds less than 15 mph. The measured values were from 92 to 98 percent of the calculated values. The differences were, as in the case of Residence No. 1, attributed to variations in the infiltration rate. For practical purposes, the comparisons show that the published values of thermal conductivities of insulation and other building materials can be utilized to obtain a good approximation of the effect of increased thermal resistance on heat loss.

The comparison between calculated and measured heat loss should not be confused with the comparison between the measured and estimated annual operating costs of electric heating systems. In well-insulated houses lighting, appliances, solar heat gains and occupants, supply some of the energy to heat the house that in an unoccupied house would have to be supplied through the heating equipment. The result of this is that the estimated operating cost must be multiplied (1) by a use factor to determine the actual annual operating cost of an electric system.

Infiltration Heat Loss

Sources of infiltration air are cracks around windows, cracks between the sill plate and the foundation wall and also through porous walls. Infiltration is caused by pressure differences between the indoors and outdoors due to wind forces or temperature differences. Infiltration through the main body of a wall can be neglected if the construction is reasonably tight. Good mortar joints in masonry construction, the use of building paper in frame construction, and careful application of insulation and proper attention to the interior finished walls in either type of construction have essentially eliminated infiltration through the walls of modern buildings. Infiltration through a poorly constructed wall cannot be calculated with any degree of accuracy.

Infiltration may be calculated either by a crack method or an air change method. The crack method consists of summing up the crack lengths of each type of window and door on one or at most two exposed sides of the building. Leakage factors are available for many types of windows and doors. The sum of the products of the crack lengths and factors is the infiltration rate necessary for heat loss calculations.

The air change method consists of assuming some number of air changes per hour due to infiltration. This method is not as accurate as the crack method if crack leakage factors are available. Where crack factors are not available the assumption of an air change rate is as reasonable as assuming a factor for the cracks.

The infiltration for entire buildings has been measured by the tracer gas technique.(3) The measured infiltration rates have shown good agreement with the crack length calculation method. The measurements were made in houses of good construction.

During the 1960-61 heating season similar studies have been made in both Research Residence No. 4 and the I=B=R Hydronic Research House. The Hydronic Research House has an exposed-beam ceiling. The ceiling construction consisted of acoustic tile attached to furring strips with 2-in. batt-type insulation above the acoustic tile. The space between the insulation and the deck roof was ventilated. Because of faulty application of the insulation, gaps were left which permitted excessive infiltration through the ceiling. There was no way to allow for this in the design load. The design infiltration load for the house was approximately 0.9 air changes per hr. Tests with tracer gas have shown that at design conditions the actual infiltration (5) was approximately 3.0 air changes per hr. Since the calculated load due to infiltration was 25 percent of the total load, the heating load was increased by 50 percent due to excessive infiltration. There is no rational procedure for calculation of the load due to excessive infiltration and the only alternative is to eliminate the cause.

The thermal resistance of Research Residence No. 4, as mentioned previously, was increased sufficiently to reduce the heat loss by approximately 30 percent. However, no changes were made to weather stripping or to any of the crackage. As a result the calculated infiltration was unchanged and the infiltration load increased from 20 percent of the original load to approximately 33 percent of the load of the modified house. With increased thermal resistance, infiltration can become a very significant part or possibly the major part of the heating load.

Effect of the Use of a Fireplace

In Research Residence No. 1 tests were conducted (6) with and without the use of the fireplace in the living room. With the thermostat located in the dining room, and with the fireplace in use, the temperatures throughout the house, except in the living room, were maintained at 72°F. The

fireplace merely acted as an auxiliary heating device. No effect on fuel consumption could be detected.

With the thermostat located in the living room and with the fireplace in operation, the open fire satisfied the thermostat and reduced temperatures in the other rooms of the house. Under these conditions some savings in furnace fuel consumption resulted from use of a fireplace but with a reduction in comfort in other rooms. No attempts were made to determine the effect of the fireplace on infiltration rates. However, it was found necessary to tightly close the opening to the fireplace when it was not in use. If this was not done, the overall effect of intermittent use of the fireplace was to increase fuel consumption due to the escape of warm air up the chimney at night when the fire was out but the flue was open.

Effect of Closing Rooms

Savings in operating costs would be expected from closing of rooms and shutting off the heat supply to those rooms. Studies were conducted (6) in both Research Residence No. 1 and the I=B=R Research Home. When the heat input from the heating unit burner greatly exceeded the heat loss of the building no reduction in fuel consumption resulted even though more than one third of the living quarters were closed off. This was due to greater losses of heat in the flue gases than occurred when all rooms were in use. Even with the correct firing rate only a small savings in fuel resulted. It was concluded that no general statement could be made with regard to fuel savings and the closing of rooms.

COOLING

The greater part of a residential cooling load is from external sources and includes heat transmission due to the outdoor-indoor temperature difference, direct solar heat gain through windows, and infiltration of outdoor air. In calculating a load for purposes of equipment selection the maximum instantaneous load from all sources would result in oversized equipment. This is due to the fact that some of the instantaneous heat gain is stored in the structure and does not affect the equipment load until some time later. In any calculation procedure (7) it is necessary that instantaneous heat gain values be averaged over periods of several hours. Studies (7,8,9,10) in several houses have provided guidance in developing the heat gain calculation procedures. Measured values of heat removed by the cooling units were utilized to select periods over which values of maximum heat transfer through walls and ceilings should be averaged and also to determine the averaging period for direct solar heat gains. Infiltration studies (3) have provided the information necessary to establish reasonable infiltration rates.

Heat gain factors for walls and ceilings are dependent on thermal resistance. Factors listed (7) for a 95°F design temperature (75°F indoors)

are: 6.1 Btuh/sq ft for an uninsulated frame wall and 7.8 Btuh/sq ft for an uninsulated concrete block or brick wall. With 2 in. of insulation the values are reduced to 3.1 Btuh/sq ft for the frame wall and 2.3 Btuh/sq ft for the block wall. The mass of a masonry wall as opposed to that of a frame wall does not necessarily affect the maximum heat transfer rate through the wall but will affect the time of day at which the maximum heat flow through the wall occurs. For example, the peak heat transfer rate through a west facing uninsulated frame wall occurs between 5 and 6 P. M. but not until after 9 P. M. through an uninsulated brick or block wall.

The thermal resistance is also important in determining ceiling heat gain factors. Ceilings under vented attic spaces have lower heat gain factors than a built-up roof and no ceiling. However, as will be shown in another section, attic ventilation is not a substitute for insulation.

Heat gain through floors over a basement or enclosed crawl space may be neglected. Houses built on slabs laid directly on the ground provide more heat storage than is available in houses with wood floors. In fact, an investigation conducted in Research Residence No. 3 (9) indicated that the cooling unit capacity requirements were substantially reduced by the "flywheel effect" of the slab floor which stored some of the heat received during the afternoon and did not release it until later in the day. Floors over unconditioned rooms must be considered (7) in heat gain calculations although the heat gain factors are not nearly as large as those for walls or ceilings exposed to higher temperature differences.

Measurements (3) of the infiltration rates in Research Residence No. 2 and the I=B=R Home have shown good agreement between measured air change rates and those calculated by the crack method. The air change rate during cooling is not as great as during heating because of the lesser indoor-outdoor temperature differences and wind speeds.

The heat gain through windows may be 50 percent or more of the total heat gain of the house depending on orientation and the total glass area and, therefore, it is important to reduce this gain whenever possible. Reductions can be accomplished with shading devices such as trees, roof overhangs, shade screen, awnings and inside shades or venetian blinds. Factors for unshaded east and west facing windows, with a 95°F outdoor temperature, may be reduced (7) from 89 Btuh/sq ft to 37 Btuh/sq ft with outside shading and to 61 Btuh/sq ft with inside shading. South facing windows (in northern latitudes) are relatively easy to shade with a roof overhang. For a 40 deg. north latitude the maximum heat gain through south facing vertical glass occurs between the hours of 9 A. M. and 3 P. M. During this period, a 3 ft - 2 in. horizontal overhang will provide complete shading at least 5 ft down the south wall.

Shading of east and west windows with an overhang is much more difficult. Maximum solar heat gains through unshaded east windows occur between 6 A.M. and 11 A. M. and through unshaded west windows between 1 P. M. and 7 P. M.

To completely shade an east or west wall 5 ft. below the overhang during these critical periods would require a horizontal projection of 9 ft.-6 in. Therefore, it will usually be necessary to rely on other shading devices to reduce the load on east and west windows.

Heat gain from internal loads should be considered. Allowances are usually made for people and for cooking. The lighting load in residences usually occurs long enough after the peak external load that it is not of concern in equipment selection.

Reduction of Ceiling Heat Gain with Attic Ventilation

An investigation (11) of the effect of attic ventilation on ceiling heat gain was conducted in Research Residence No. 2 during the summer of 1956. Residence No. 2 was a well-constructed one-story house with a large amount of glass area and a full basement. The Residence had a floor area of 1040 sq. ft. and the sidewalls and ceiling were provided with 3-5/8 in. mineral wool insulation. The calculated heat gain of the entire house was 22,500 Btuh of which the ceiling gain was 4,160 Btuh or 24 percent of the total. Ventilation air-flow rates through the attic were 0.2, 0.6, 1.0 and 1.5 cfm per sq. ft. of ceiling area. The rate of 0.2 cfm per sq ft was the natural ventilation rate through the attic ventilators. The higher air-flow rates were provided with an attic fan which was thermostatically controlled to cut-on when the attic temperature reached 85°F and to cut-off when the temperature dropped to 75°F. The instrumentation included thermocouples to measure attic air temperatures, heat flow meters to measure the ceiling heat-flow rates and a calibrated nozzle to measure the air-flow rates.

Table 4.--Reduction of maximum ceiling heat gain on a design day

(Outdoor Temperature 95° F. Clear Sky)

Ventilation Rate Cfm/sq. ft.1/	Maximum Attic Temperature °F.	Maximum Ceiling Heat-Flow Rate, Btuh/Sq. Ft.	Relative Rate Percent
0.2 (Natural)	127.5	3.58	100
.6	121.0	3.08	86
1.0	115.5	2.66	74.2
1.5	107.5	2.05	57.3

1/ Based on ceiling area.

The effect of the ventilation rates on the maximum attic temperatures and the maximum ceiling heat-flow rates is shown in Table 4. Increasing the ventilation rate from the natural rate of 0.2 cfm per sq ft of ceiling area to the maximum of 1.5 cfm per sq ft, reduced the heat-flow rate by approximately 43 percent. Since the ceiling gain was equal to 24 percent of the entire house heat gain, the reduction was equal to approximately 10 percent of the total sensible load. Since the ceiling of Residence No. 2 was fully insulated, the reduction in the design maximum ceiling heat gain resulting from attic ventilation amounted to only 1780 Btuh with the highest ventilation rate. This was not large enough to permit the installation of a smaller summer air conditioning unit. To determine the reduction that would occur with lesser amounts of insulation and also to compare the effects of insulation and ventilation, the ceiling heat gain was calculated for a comparable house (ceiling area = 1040 sq ft) with ceiling insulation thicknesses of 0 and 2 in. and 3-5/8 in. The heat gain factors for natural ventilation (0.2 cfm per sq ft) were obtained (12) from the National Warm Air Heating and Air Conditioning Association Manual No. 11 for design conditions of 95°F outdoor temperature, a mean daily temperature range, and an indoor temperature of 75°F.

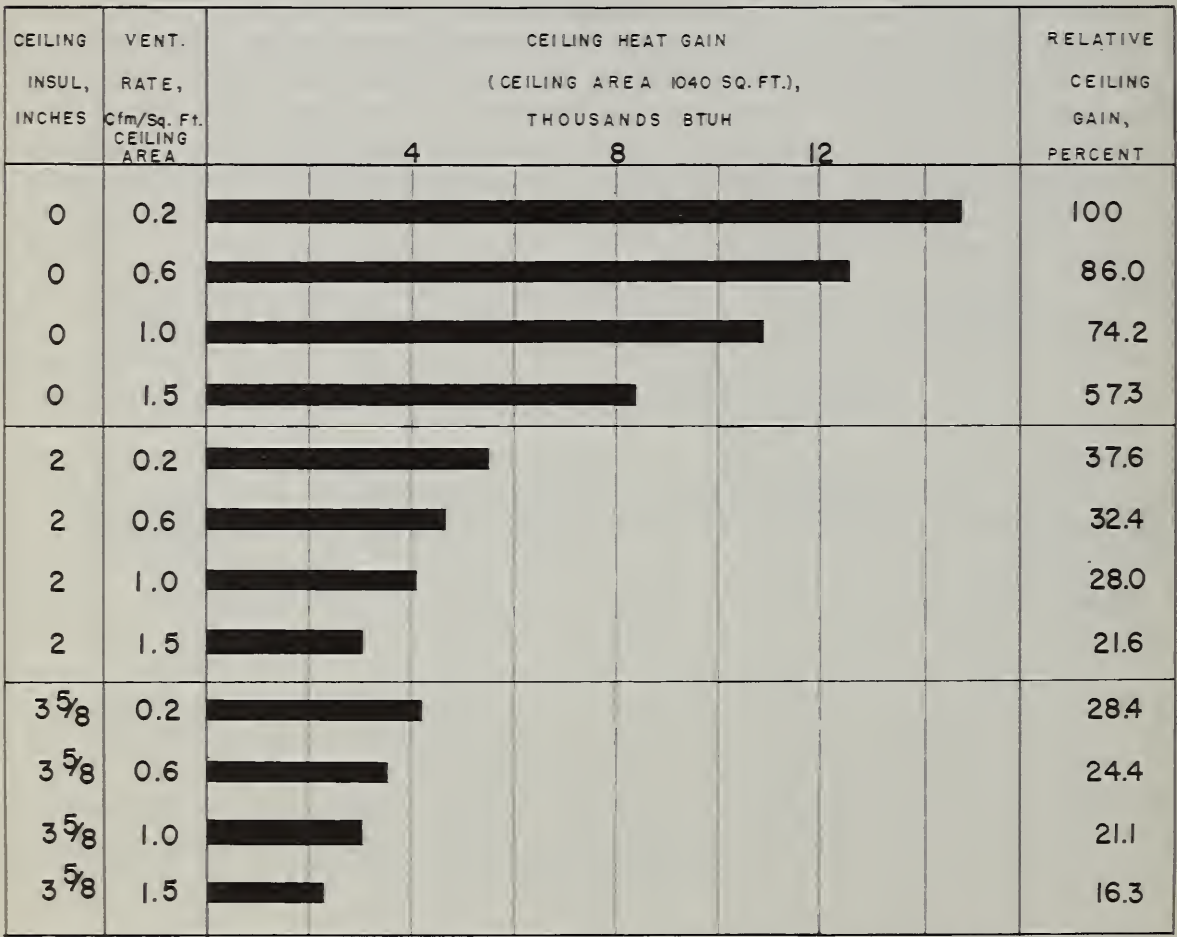

FIG. 2 COMPARISON OF EFFECTS OF ATTIC VENTILATION AND INSULATION ON CEILING HEAT GAIN.

It was assumed that the percent reductions in ceiling heat gain with full insulation, as determined in the investigation with full ceiling insulation, would also be applicable to lesser insulation thicknesses. The calculated values of ceiling heat gain for the three insulation thicknesses and four ventilation rates are shown in Table 5 and Fig. 2. The relative gains are

Table 5.--Calculated reduction of design ceiling heat gain in Research Residence No. 2 for various combinations of insulation and ventilation

Ceiling Insulation In.	Ventilation Rate Cfm/sq. ft.	Design Ceiling Heat Gain[1/] Btuh	Relative Ceiling Gain, Percent
0	0.2	14,660	100
0	0.6	12,600	86.0
0	1.0	10,860	74.2
0	1.5	8,400	57.3
2	0.2	5,512	37.6
2	0.6	4,750	32.4
2	1.0	4,100	28.0
2	1.5	3,160	21.6
3-5/8	0.2	4,160	28.4
3-5/8	0.6	3,580	24.4
3-5/8	1.0	3,090	21.1
3-5/8	1.5	2,380	16.3

1/ Based on heat gain factors given in National Warm Air Heating and Air Conditioning Association Manual No. 11, measured reduction in attic temperature and heat-flow rates from the investigation, and ceiling area of 1,040 sq. ft.

based on a ceiling gain of 100 percent with no ceiling insulation and natural attic ventilation. From the calculated heat gains it was concluded:

1. The use of 2 in. of insulation and natural attic ventilation caused a greater reduction in heat gain than the maximum forced attic ventilation rate without insulation.

2. The use of 3-5/8 in. of insulation and natural ventilation resulted in the same ceiling heat gain as 2 in. of insulation and a forced attic ventilation rate of 1.0 cfm per sq ft of ceiling area.

3. Without any insulation the maximum ventilation rate would reduce the sensible load by 6200 Btuh. With 3-5/8 in. of insulation the maximum ventilation rate reduced the heat gain by only 1780 Btuh. With greater insulation thicknesses the reduction with ventilation would be even less. The table shows that attic ventilation should not be used as a substitute for insulation.

<u>SUMMARY</u>

1. Where insulation is added to reduce heat loss of a house it is not sufficient to specify only the insulation thickensses. It is better to specify a heat loss per sq ft of floor area and apply insulation as required to reduce the heat loss to the required level.

2. Studies conducted in Residence No. 4 indicated that measured heat losses were in good agreement with calculated heat losses. This should not be confused with estimated annual operating cost and measured annual operating cost of electric heating equipment. Part of the annual heating load is supplied by lighting, appliances, solar heat gains and occupants which reduce the amount of energy that must be supplied directly through the heating equipment.

3. Excessive infiltration may increase heat loss by 50 percent or more.

4. Infiltration may become the major part of the heat loss as insulation thickness is increased.

5. In the calculation of cooling loads, instantaneous heat gains must be averaged over a period of several hours to account for storage effects and time lag of the structure.

6. Direct solar heat gains through windows may account for 50 percent of the cooling load and it is important that these gains be reduced by shading wherever possible.

7. Ceiling heat gains may be more effectively reduced by the addition of insulation than through the use of attic ventilation.

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ECONOMICS OF INSULATION

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Within the past year or so, a number of articles have appeared both attacking and defending the amounts of insulation used in electrically heated and cooled homes. Comments ranging from the attitude that insulation causes more trouble than it is worth and is only a necessary evil which must be tolerated, up to recommendations of almost unheard of quantities of insulation, have been voiced.

The sum total of all of this, is that a degree of doubt as to how much insulation should be used is becoming apparent. Therefore, some time spent on analyzing and discussing the relationship of electric heating and insulation would seem well worthwhile.

It is logical to start with the consideration of what is being done today -- How much insulation is being recommended by the power suppliers? How much is suggested by the manufacturers of electric heating and cooling equipment and of the insulation industry itself?

From what we heard yesterday the All Weather Comfort Standard with its corresponding R values of 19, 11 and 13, is overwhelmingly being advocated by the power suppliers. Of those indicating to EW magazine (Electrical World) their R number recommendations, the average ceiling R value is 19.87; in walls the average is 11.32. So it would seem that the AWCS insulation recommendations are being closely followed by power suppliers.

Similarly, the manufacturers of insulation and heating and coding equipment have responded with their endorsement of these same R values. While not all are in agreement, again, a large majority feel that these levels of insulation are in order.

The 6-4-2 slogan, which did so much to popularize electric heating in its infancy, improved by the use of the R-system of measuring installed performance rather than thickness, plus the AWCS surely seems to be today's insulation practice.

There has been little or no quarrel with the thought that these levels of insulation are highly desirable, both from promotional and technical aspects. Few people advocate lesser amounts, for when the amount of

insulation dictated by electric heating alone is less, air conditioning certainly requires the difference.

Opposition to this amount of insulation is heard, however, from some quarters -- proposing extra thicknesses to total up to 14 inches in ceilings, 8 inches in walls and 12 inches in floors. With common insulating materials these proposals would mean R's of up to 50 or more in ceilings, 30 in walls and over 40 in floors. Since we have already established what the generally accepted amount of insulation today is, let us examine these "extra-thickness" proposals in comparison to this level.

First, let us look at them from the aspect of the builder. In today's highly competitive housing market, initial cost to the builder (who naturally must pass this on to the buyer) is extremely important. For the builder, construction costs for electric heating must be very close to that of competing systems. In perhaps oversimplified terms, the cost of the heating equipment plus the insulation, must be about the same for any system. This enables him to sell his house at a competitive price in the open market. Expected higher operating costs, if reasonably competitive would appear not to be a liability. This is witnessed by the healthy growth rate of electrical heating today. While the use of extra thicknesses of insulation will reduce this anticipated annual operating expense, at the same time the problems raised to the builder may often be distinctly undesirable. The builder who considers improving the thermal values of his house by using great thicknesses of ceiling insulation for example, may find that the would-be-buyer's reaction is one of apprehension. Seeing these quantities in the ceiling, the prospect's immediate thought may well be that electric heating is quite expensive after all. (He had suspected this all along, but the power supplier had helped allay that fear). Why else would this extraordinary quantity of insulation have been put in? Whether the builder <u>was</u> doing what was best for the buyer at that point is moot. What matters is that he just lost a prospect, probably forever, to his competition.

Similarly, the builder might decide to use deeper wall studs to accommodate the "extra thick" insulation. The additional construction costs of heavier framing, greater outside dimensions, deeper trim and more insulation must be passed on to the buyer. Since, with normal practice, almost twice as much of the wall heat loss is already through windows and doors, the builder would appear to be putting a third lock on the front door, while leaving the back one only on the latch.

The proponents of "extra thick" insulation also point to the corresponding reduction in equipment costs. This is certainly true when a comparison of a well insulated house is made to one with little or no insulation. However, installing "extra thick" insulation rather than today's accepted levels may reduce equipment costs very little, if at all. If the entire house has a heat loss of somewhere under 9 kilo-

watts, for example, by the time each room has been sized, a total of 10 kilowatts of equipment might be installed. "Extra-thick" insulation would reduce the calculated heat loss to about 7 kilowatts; but at the same time, because of the standard wattage output of the equipment, only a portion of this equipment saving might actually be realized. Differences in the calculated kilowatt heat loss then are not always readily translated in terms of reduced heating equipment. Similarly, the "extra-thick" insulation would probably not reduce the cooling unit required from 2-tons to 1½-tons. The reduction in heat gain through the insulated sections becomes secondary to overhangs and shading of glass areas. It may then be seen that while the theory of equipment reduction is true, it is often difficult to fully attain in practice, once the house has been insulated to today's accepted level.

Since the builder and the power supplier obviously have much in common in the promotion and sale of electric heating and cooling, let us next examine the position of the power supplier. The supplier is in the unenviable position of having to vie with one or more powerful competitors. He has to sell house heating (the same thing they are selling) but he would appear to already have two strikes against him at the start. His competition is well established in the business--strike one. At the same time, his product will probably cost the purchaser more--strike two. But with over 700,000 installations already on the lines, and estimates of 4 million more within the next decade, it doesn't appear that he seems concerned about striking out very often. Is electric heating just a spring training whiz, or is he big league? He's betting literally millions of dollars that he'll make the majors.

Why is electric heating so sure? It's not very hard to establish this. Electric heating is using the strikes against him as promotional assets and not liabilities. What has he done with strike one--being a latecomer? Electric heat promotion stresses flexibility, safety, room by room control, no service, low initial cost, convenience, efficiency, ease of control and primarily "the ultimate in year-around comfort." He has taken this late entry in stride, and used it to his advantage, by being "modern."

Strike two -- probable higher operating costs. His competition at first thought this would surely slow him down--but it hasn't. Electric heat has sold at higher operating costs, because it has been effectively promoted as being better--not cheaper. It has proven that it can successfully compete today -- not dollar for dollar necessarily, but for its share of housing starts.

Electric Heat and Air Conditioning magazine's annual Market Analysis issue reports an increase of 127,600 electrically heated homes between September 1, 1959, and September 1, 1960. (Thirty-four percent have some form of air conditioning, by the way). The analysis further shows an average annual heating cost of only $127. This figure varies from $105 in the Southern States to $224 in the Northeast.

Current insulation practices have helped produce these competitive operating costs, and certainly have aided in this rather extraordinary increase. Whether "extra-thickness" insulation would aid or hinder this growth is far from clear. This new major-leaguer is making the big time. His average is doing fine. It may not be very wise to change his batting stance from the power supplier's view right now.

Now that the power supplier and the builder have the house ready, we come to the heart of the matter. This, of course, is the buyer, the man who must be sold. Obviously, the buyer must like electric heat, or he wouldn't be buying it at the rate he is now. Again, current insulation practices have certainly helped, not only in regard to operating expense, but also to comfort. Electric heat couldn't deliver on its promise of being "better" without sufficient insulation to produce a high level of comfort. While this comfort may certainly be partly attributed to multiple glazing, storm doors and weatherstripping, insulation provides comfortable wall, floor, and ceiling surface temperatures. Without them, drafts and discomfort become apparent.

A typical uninsulated wall would have an inside surface temperature of about 59 degrees when the outside temperature is zero and the inside air is 70. Using R-11 wall insulation, this surface temperature would be almost 67 degrees. This is certainly a highly desirable comfort level. An increase from R-11 to about 28 (using 2x8 wall framing) will increase this surface temperature only about one degree. It seems reasonably certain that this change will not be felt by the occupants. "Extra-thick" insulation has for all intents and purposes not improved the level of comfort perceptibly.

Since the two prime functions of insulation are comfort and economy, an examination of further operating economies by using "extra-thick" insulation remains.

To date, there are no hard and fast answers to the question of the economics of insulation as it relates to the homeowner.

Many of the factors involved have been previously cited, but a review of them is necessary to evaluate the problem. For any greater amount of insulation to economically justify its use, the cost of doing the work, minus any savings in equipment, must be equal to or be less than the anticipated operating savings. Let's look at that again, taking it a bit more slowly.

The cost of doing the work is the first part.

This includes the cost of installing the additional insulation, as well as the cost of any construction changes made necessary by the extra insulation. Since this cost will be added to the mortgage, the interest rate and amortization period must be considered.

Since the average new home buyer remains in the house only about nine years and then moves, it would seem inconsistent to attempt to amortize the cost of the additional insulation over the entire expected life of the building. It is only reasonable to expect that the man who pays for the additional insulation, should at least recover his investment while occupying the home. The resale value of a seventh or eighth inch of insulation is questionable. A period of 10 years as the amortization time therefore would seem appropriate. Should the owner stay in the house past this period (and obviously only about half do), then he would benefit from additional savings in operation each year.

The first part of our equation -- the cost of doing the work -- is therefore easy to evaluate if there are no construction changes required. It is simply the cost of the additional insulation multiplied by the cost of money per year (the interest rate being assumed constant), over a ten-year period.

The second part was referred to previously -- the possible reduction in equipment cost. If the winter losses and summer gains of the house are calculated for both insulation levels, the actual reduction in cost would be the difference in equipment size, multiplied by the cost per unit of equipment. This may be directly subtracted from the expense of the added insulation before the cost of money enters in.

The variables in these first two parts may be estimated with a fair degree of accuracy for a given application.

However, the third part of the equation poses some distinct problems. This is the anticipated yearly savings in operating costs.

Where cooling savings are concerned, there are wide disagreements as to how they may be computed. The unified industry heat gain procedure (soon to be released) will make it possible to determine the differences in cooling loads for different levels of insulation with some consistency. However, the operating cost (or savings) calculation procedures available are still largely in conflict.

On the heating side, the situation is similar. While acceptable procedures for determining the differences in heat loss for varying amounts of insulation are readily available, reliable formulae for operating costs are not. NEMA and FHA both recognize this by the introduction of constants. Both admit that these constants are not constant. Sufficient information is available to show NEMA "C" values ranging from 10, or somewhat less, up to 18.5.

Many opinions have been offered as to why this "C" factor should vary over such a wide range. Internal heat gain from occupants and appliances, solar radiation and the thermal design of the house appear to be some of the reasons. One must also realize that the habits of the occupants have a distinct effect on operating costs, hence this elusive inconsistent

"C" factor. As was shown yesterday, it is possible to measure some of the variables and even simulate occupancy to a degree. These things alone, however, are not enough. Using today's methods of calculating operating costs (and therefore, savings) for different degrees of insulation, still leaves the engineer with a varying "C" looking straight at him. We are doing an injustice to the owner if our "C" estimates are largely in error when we estimate operating savings. To date, the electric industry has approached this problem by "building in" a safety factor. "When in doubt, use 18.5," is generally heard. This leads to operating estimates that are usually higher than the actual later billing. The sales advantages of this approach are obvious. The same reasoning would lead to the use of a very low "C" factor when calculating expected operating savings. The same factor which gave a high estimate of operating costs, would logically produce a high estimate of savings in this case. These savings may, or may not be realized in the actual installation. If they are not, then the owner has not received his investment back.

The last variable is the power rate for space heating. The market analysis referred to earlier showed that within the year of September 1, 1959, to September 1, 1960, fifteen percent of 183 systems reporting reduced their heating rates. Three percent increased them. The net change was a reduction in the heating rate averaging 11 to 12 percent for those systems indicating rate revisions.

To be assured that the homeowner at least will regain his investment in the amortization period, the average house heating rate for the entire period should be assumed. It would seem in many cases, to require a large degree of clairvoyance to anticipate the house heating rate our owner friend will have to pay ten years from now.

So it would appear that the number of variables involved makes the economic selection of insulation no easy task. It is not, however, impossible to establish some guideposts along the way. Some of these are rather obvious, but restating them is still worthwhile:

(1) <u>Any</u> additional amount of insulation <u>will</u> help reduce the operating costs of electrically heated and air conditioned homes. Remember, however, that the ninth or tenth inch will not help as much as the fifth or sixth, although it may cost just as much.

(2) Careful analysis will indicate that homes, which are heated only, should use less insulation than similar homes which are both heated and cooled.

(3) Thermal insulations -- that is to say the products which are specifically sold as such -- are only a part of the over-all economics of constructing, heating and cooling a home. Glazing and doors must certainly be

carefully evaluated in an equally critical light, since they have considerable effects on heating and cooling equipment requirements and operating costs.

(4) For electric house heating and cooling to grow, it must be sold. People buy houses, not theories. For electric heating and cooling to reach a large market, not only must its anticipated operating costs be reasonably competitive; the initial cost of heating equipment, insulation and construction must be almost directly so. These two considerations must be taken together. A significant increase in initial cost, with the idea of reducing operating costs may be just as detrimental as using minimal insulation just for the sake of a lower sales price. The balance of these two elements (which vary throughout the country) is what is necessary for growth and acceptance in the low and medium cost markets.

All of these factors are not unique to electric heating and cooling. The growing pains are just that and no more. Rather, in fact, the present looks good and the future even better for electric heat. The current growth rate is really remarkable. That it can compete with other energy sources is obvious; consider these two statements:

Mr. Richard C. Wright at a recent convention of the National Oil Fuel Institute commented, "What are some of the heating needs the public feels are better supplied by electricity?" He answered with the statement that it certainly was not economy. He went on to say, "It must, therefore, be something else. We had better find out for sure what it is. Probably, impressions of convenience, cleanliness, safety, and prestige are involved."

Mr. W. H. Loving at an American Gas Association Research and Utilization Conference a few weeks ago stated, "There is no reason to think that a good bit of electric heating equipment will not be sold during the years to come. Anything can be sold if the salesmen are aggressive and the advertising is effective. Many of you can remember back in the 1930's when gas heat was sold against oil at 6¢ per gallon. In spite of the fact that gas heat was a luxury, with an operating cost nearly twice that of oil, we sold thousands of jobs...."

It certainly would seem that with two strikes against it, electric heat is in a better position than perhaps we think. From the above two comments, it would seem that it is the competitive pitchers who are alarmed.

INSULATION AND ITS USE IN THE HOME

by

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Introduction

An important development in modern construction practices is the increasing use of thermal insulation in all types of houses. Comfort is usually the basic objective in the use of insulation, but fuel economy is perhaps the motivating factor in the amount used. During cold weather, insulation helps to maintain uniform temperatures. During hot weather, insulation helps to keep indoor temperatures lower than they would be in an uninsulated house. Houses with properly insulated walls, ceilings, and floors, furthermore, require smaller heating plants and smaller capacity cooling units.

Thermal Insulation

General

Most materials used in the construction of walls, floors, and roofs of dwellings offer some resistance to the passage of heat. Materials having a high resistance are called thermal insulators or, more commonly, insulation. Wood might logically be classed as an insulating material, for example, because a 1-inch thickness of wood is equal in resistance to heat transmission to about 12 inches of concrete. When the wood is made into a fibrous product of low-to-moderate density, however, it becomes far superior to solid wood in thermal properties.

Insulation is rated on its "k" value, or conductivity, which is the amount of heat in British thermal units that will pass in 1 hour through 1 square foot of 1-inch-thick material per degree Fahrenheit difference in temperature between the material's two faces. Thus, the lower the "k" value, the better resistance the material has to the passage of heat.

1/ Maintained in cooperation with the University of Wisconsin.

The various kinds of insulation may be grouped as follows: (1) flexible, (2) fill, (3) reflective, and (4) rigid.

Flexible Insulation

There are two general types of flexible insulation used to insulate houses--blanket or batts. Both are made to fit between framing members spaced 16 or 24 inches on center. Blanket insulation, 1 to 3 inches thick, is ordinarily made with a vapor barrier material on the front face. The blankets come packed either in roll or accordian-pleat fashion. Batt insulation is usually 3 to 6 inches in thickness and is made in lengths of 2 or 4 feet, or longer. The batts also are made with a vapor barrier material on the front face. This vapor barrier usually consists of such materials as asphalt-coated paper or aluminum foil. A good vapor barrier material is of prime importance.

Flexible insulation may be made of cotton fiber, of a mineral wool form of glass, slag, or rock, of wood fiber, or of other materials. The "k" values of blanket or batt types of insulation generally range between 0.25 and 0.27.

Fill Insulation

Insulations that are poured or blown into wall spaces or attic areas are called fill insulations. They may be granules of expanded mica (vermiculite) or marble-sized pellets of mineral wool or glass fiber. The "k" values for fill insulations are slightly higher than those for blanket and batt insulations made of the same material. For example, a material that has a "k" value of about 0.27 when used in blanket and batt insulation would have a "k" value of approximately 0.30 when used in a fill insulation. Thus, fill-type insulations are not so efficient as blanket and batt types. The "k" values for fill insulations made of wood or mineral fibers range between about 0.28 and 0.30, while for those made of vermiculite, the "k" value is about 0.48.

Reflective Insulation

Most materials reflect radiant heat, and those that have this property to a high degree can be used in enclosed stud spaces, over crawl spaces, and in attics to retard heat transfer by radiation. The most common types are aluminum foil in single sheets with either one or both sides having reflective surfaces and the accordion type. To be effective, these must be installed with a reflective surface facing or exposed to an air space, preferably 3/4 inch or more in width. Reflective materials in contact with other surfaces lose their reflective properties. The resistance or "R" value of a single sheet of aluminum foil with two reflective faces is 4.3. This is equivalent to slightly more than an inch of flexible insulation with a "k" value of 0.27.

Rigid Insulation

Rigid insulating material is often a fiberboard made from processed wood or vegetable products. It is manufactured in 2- by 8-, 4- by 8-foot, and larger sheets in 1/2- and 25/32-inch thicknesses for use as sheathing. This type of rigid insulation is also laminated into sections 1-1/2 to 3 inches thick for use as roof decking over supports spaced up to 4 feet apart. In this form, it is used in the roofs of houses with post and beam construction. Thus, it serves as an interior finish, as an insulation, and as a sheathing base for a built-up roof. Vapor barriers are often incorporated into the laminated sections. The "k" value for this type of insulation is about 0.40 to 0.42.

The use of wood as insulation must also be considered when nominal 3- or 4-inch-thick roof decking is used. Supports for wood roof decking may be spaced 10 or more feet apart. Wood species, such as the cedars, the soft pines, and redwood, are often used in double tongue-and-groove patterns. The "k" values for these woods average between 0.60 and 0.75.

Foamed plastics, such as polystyrene, are being used to a great extent in certain locations. They are especially adaptable for use on solid masonry walls because they serve both as insulation and as a plaster base. Most foamed plastics are useful as vapor barriers because they resist the movement of water vapor. Materials of this type are also used as perimeter insulation in concrete slab houses. The "k" value for these insulations is about 0.29, although some manufacturers claim a "k" value as low as 0.24.

Insulating Values

In the selection of insulating materials and the establishment of an overall "U" value for walls and ceilings, the thickness of the insulation is the primary factor if "k" values range between about 0.25 and 0.27. The value of "k," or the conductivity, is the insulating value of each section, space, or the two surfaces of a wall, ceiling, or floor. The "U" value, in brief, is the summation of all individual values of the wall, floor, or ceiling section. In actual practice, it is customary to add all resistances which are $\frac{1}{k}$ (per inch) or $\frac{1}{c}$ (per unit) to arrive at a total resistance, R. The reciprocal of the overall resistance, $\frac{1}{R}$, is the "U" value.

It is, of course, important to have as low a "U" value as practical to decrease heat loss and save fuel. This is especially true of electric heating. Much can be said, however, about a balance of insulating properties. For example, if a "U" value less than 0.06 is desired in the wall, it is also advisable to keep the "U" value

of windows and doors as low as possible. This may require triple or even quadruple glazing, as even double glazing will allow 10 times the heat loss as the desired 0.06 "U" value for the walls.

The differences in uninsulated and insulated walls are shown in the following example:

A conventional wood-framed wall with wood siding, gypsum sheathing, and plastered interior finish has a "U" value of about 0.27. By adding full thick (3-1/2 in.) blanket or batt insulation, this "U" value is reduced to less than 0.06. This means that the insulated wall has 4-1/2 times the insulating value of that of the uninsulated wall.

Installing Insulation

Insulation should be placed in all exposed walls, ceilings, and floors, over crawl spaces, and around the perimeter of houses constructed on concrete slabs. Because of the increased use of summer air conditioners and the development of better methods of heating by electricity, proper placement as well as the correct amount of insulation is important.

In the past, 1 to 2 inches of insulation in the walls and 4 inches in the ceilings were considered a sufficient amount. The trend is toward full-thick (3-1/2 in.) wall insulation and 6, 8, and even 10 inches in the ceiling area. A number of electrically heated test houses were constructed in Salt Lake City using both 2- by 4- and 2- by 6-inch studs with full-thick insulation. The use of large amounts of insulation accentuates the need for an excellent and properly applied vapor barrier. The use of more insulation results in colder surfaces on the back faces of sheathing and siding, which can cause the formation of condensation and frost if the vapor barrier is eliminated or improperly applied.

Special attention should be given to insulating the spaces in outside walls behind the edge studs of intersecting walls and in the floor and ceiling areas adjoining outside walls. These areas are only protected by the thickness of the header or stringer joist and the sheathing and siding material. Areas around windows and outside doors also require special attention.

The application of fill insulation in older houses without a vapor barrier often results in condensation problems. Such problems can be prevented by (1) reducing vapor sources, (2) insuring good attic ventilation, (3) using exhaust fans, and (4) applying paint barriers on the inside surfaces of outside walls where possible. Good insulation in the ceiling area, together with adequate attic ventilation, will result not only in the elimination of ice dams in the winter because of lower attic temperatures, but also in added comfort in the living areas during the summer.

FOAMED-IN-PLACE INSULATION

by

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We have all observed and applauded the tremendous technological advances in power generation and the utilization of energy throughout the years. Of prime importance to us today is the evolution of energy conversion for the purpose of generating heat and air conditioning for houses. We have seen heat generation evolve through wood, coal, oil, gas and now finally electricity. This evolution has placed the stress on more efficient, more sophisticated, more controlled methods of heat, not the generation of more heat. I think we should use this same philosophy in considering the materials that are required to contain and prevent the loss in heat. In this field of thermal insulation our thoughts should be directed more towards increasing the efficiency of insulation as compared to just a greater volume of conventional insulation. We are reaching the optimum in quantity of insulation that can be practically employed in house construction; therefore, it would be desirable to have an insulation material that would provide the superior barrier to heat flow required with electric heating and still have it fit into our conventional wall construction. This is possible today because along with the evolution of heating systems some important technological advances have been made in the field of insulation. We can now shift our thinking from materials having thermal conductivity in the range of 0.25 or 0.30 Btu/hr./sq. ft./^{o}F./in. ("R" = 3.5 to 4.0) to that material with a "K" factor of 0.14 (R = 7.0).

Mention of such "R" values brings me to the direct subject of my paper - urethane foams. I am limiting my remarks to the urethanes because it is the only material that can be truly foamed-in-place in the field. I will not dwell at length on the chemistry involved in urethanes. The significant difference to the end user will be that on his order for building materials he will find insulation being delivered by the gallon instead of the board feet. Urethanes will arrive on the job in the form of two liquids. These liquids must then be mechanically mixed and applied to the structure. This foaming reaction is easily demonstrated and occurs in a matter of seconds.

Because they are available as liquids, urethanes, after mixing, can be cast into cavities or by means of commercially available equipment be spray - applied to the desired surface.

Why are urethanes important to the designer, the builder, and the homeowner of an electrically heated or cooled house? As mentioned previously, urethane's first contribution to better insulation practices is its extremely high "R" value. The following table spells out this difference when compared to conventional insulating materials.

INSULATION PROPERTIES

Material	Resistance*
Expanded mica - loose fill	2.08
Cellular glass - board	2.50
Mineral wool - loose fill	3.33
Cork Board - board	3.70
Mineral and glass fiber - batt	3.70
Styrene foam - board	4.00
Urethane foam - sprayed and board	7.05

*Based on 1" thickness

It can be seen from the above data that where an over-all installed "R" value of 19 is required that less than 3" of urethane will fill this requirement and therefore readily fit into the normally available 3-5/8" space in conventional 2 x 4 framing.

Another important property that urethanes possess is its high resistance to moisture penetration. Sprayed urethane foams have a moisture permeability rating between 1.0 and 2.0. In addition, urethane foams are completely unaffected by moisture, thereby eliminating the possibilities of dry rot, mildew,and the usual deteriorating effects of water. Since urethane foam would normally be applied in thicknesses of 2" or greater, it provides a uniform, thick effective vapor barrier. This is of importance when consideration is given to the desirability of moving the affecting vapor barrier from one side of conventional insulation to the other when changing from a heating system to a cooling condition in the house. Since the vapor barrier properties are available throughout the thickness of the foam, it will be as effective under either operating condition.

Another important consideration to be extended the use of urethane foams is the possibility of greatly reduced, if not eliminated, infiltration losses. Its impermeability coupled with the method of application which permits it to be applied on all surfaces offers the opportunity to effectively eliminate the normal paths of air movement through the wall. Because urethanes are self-bonding to mort substrates, it is in intimate contact with all the surfaces to which it is applied.

Since modern spray techniques are used, urethane foam can be applied at very fast rates. On the limited studies made to date an average 1500 sq. ft. house can be spray insulated with urethane foam in approximately two hours.

Because of its own structural strength and rigidity and its very good adhesion to the surfaces to which it is sprayed, urethane foams will lock the individual components of construction such as framing, sheathing, electrical wiring and plumbing into a monolithic structure. This results in a much more sturdy and tight construction.

Urethane foam's ability to withstand temperatures up to 250°F. permits it to be used in areas directly in contact with most conventional heating systems. It can, therefore, be placed directly behind baseboard or

wall type heaters and not be affected by the temperature.

The following table summarizes the above detailed advantages for the use of sprayed urethanes in home construction:

ADVANTAGES OF SPRAYED URETHANES

1. Greatly increased "R" values
2. Unaffected by moisture
3. Reduction of infiltration losses
4. Speed of spray application
5. Contribution to structural integrity
6. Withstand temperatures up to 250°F.

In January 1961 two conventional development type houses were spray insulated with urethane foams. Figures 1 and 2 indicate the type of application employed. Both employed electrical heating, one using the embedded cable and the other an electrical furnace with forced draft distribution. Records are being maintained as to the power consumption in heating these units. Currently, the use of urethane foams for thermal insulation will cost more than conventional insulation. However, several economic credits are possible when full utilization of urethane foams is achieved. For example, properly designed urethane foam can eliminate sheathing in a brick veneer house. The credit hereby realized could well bring the economics of urethane foams into direct competition with conventional material. More importantly, however, as has been pointed out, urethanes do not require any basic change in house construction. This means that to get the over-all resistance of 19, it is not necessary to resort to the obviously expensive approach of building with 2 x 6 or 2 x 8 that would be required when conventional insulation is used.

To further establish the versatility of urethane foams in the construction industry, I would like to mention several other applications. Urethane foams can be effectively employed as a foamed-in-place filler for insulated masonry cavity walls. Use of urethanes in this instance reduces the "U" factor from 0.35 for non-insulating cavity to 0.06. This makes possible a significant reduction in heating and air conditioning equipment cost as well as operating cost. In addition, the presence of the well boning urethane foam greatly strengthens the cavity wall and permits greater flexibility in architectural design. Foam also acts as an effective barrier to the passage of moisture throughout the cavity.

It is also possible to use urethane foam as a core for sandwich panels, both load bearing and non-load bearing. Curtain wall paneling made with laminated urethane slab stock is now a commercial reality and other variations of the urethane sandwich panel will soon make their appearance.

In addition to sprayed foams being applied to residential construction, there would also appear to be a large market for such material on farm buildings using the so-called "skin and bones" construction. The use of sprayed urethanes would permit sealing off of the building from the

Figure 1.--Urethane foam insulation sprayed in thin layers quickly foams into cellular structure filled with insulating gas. Foam adheres firmly to walls and framing (A), seals tightly at door, window frames, and sills (B).

elements prior to the application of insulation. This, coupled with the speed of application, could greatly reduce the field construction time for such buildings.

What I have tried to do this morning is to point out that technological advances have now made available an insulating material approximately 2 to 3 times as effective as any on the market today. In addition, it possesses the economic capabilities of being manufactured and being applied in place. Because of these features, I believe that urethane foam has a fine potential in the construction of electrically heated and/or cooled houses.

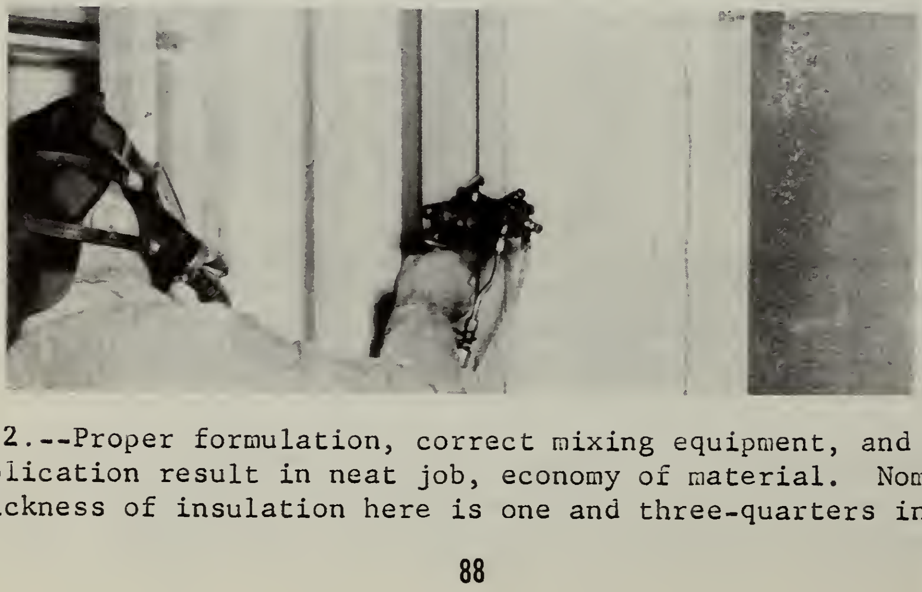

Figure 2.--Proper formulation, correct mixing equipment, and skillful application result in neat job, economy of material. Nominal thickness of insulation here is one and three-quarters inches.

CLOSING REMARKS

by

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On behalf of the Agricultural Engineering Research Division of the Agricultural Research Service I want to thank the participants in this conference--both those who gave papers and those who attended. The conference topic is timely and because there are still many shrewd estimates used in our calculations of heat loss, heat gain, and moisture transfer, it is a topic which can be clarified by exchange of ideas like those discussed.

It is encouraging to realize that, when a challenge to find an answer to perplexing engineering problems is put before industry and research organizations, it takes only a few years to take some very effective steps towards the solution of these problems. As I see it, the main problem of challenge about 15 years ago was, "How can the convenience and flexibility of electric heat be made available to the farm home owner?"

The answer came in a multiple set of propositions:

1. Furnish electric power cheaply.

2. Insulate the home well to require lower heat input than that used in the normal home.

3. Tighten the windows and doors to prevent the loss of heat through excessive infiltration.

4. Extract heat from the soil, the air, or the ground water to use it in heating the home.

5. Supplement the heat furnished by electrical power by collecting, storing, and more efficiently using the natural heat of radiation from the sun.

Men have worked diligently on each of these topics, and as usual in research, the findings apply to broader fields than the original aims envisioned.

Mr. Coblentz's development of an instrument to measure helium concentration as a means of infiltration measurement is a great forward stride because it gives the first data on actual air leakage of a completed house. These data compared to wind velocities and directions, construction type, and temperature differentials are powerful tools in the hands of research engineers like Brown, Erickson, and Warren S. Harris, research professor of mechanical engineering at the University of Illinois. From these figures we know more accurately the actual heat losses and gains from air exchange and therefore can design with narrower "ignorance" factors and consequently with greater economy.

This conference, dealing with heat, moisture, and air exchange between a house and its external and internal environment, has about as much implication for houses heated by coal, oil, or gas as it does for those heated by electricity. Power industries are to be congratulated on their interest and pioneering work in heating and cooling with electricity. They are the logical industry to take such action for, in electrically heated homes, economy demands that crude approximations in design, and half-hearted attempts to insulate, be eliminated.

As indicated by Mr. Boyd and Mr. Smithman, an ordinary uninsulated house can require an oil bill comparable to the electrical bill for heating a similar house that is well insulated and weather sealed.

Since actual field studies have shown this to be true, then why was this conference called? I believe it was called for a complex of several reasons. In the first place, electrical heating has been successful enough times to make it somewhat of a trend. Electric heating and cooling are natural adjuncts to each other; with increased emphasis on summer cooling, electrical heating follows. The number of installations are rapidly increasing. In this healthy climate of growth, socially minded men naturally like to get together to discuss the good features -- the motives being pride in success, advertisement for continued growth, a sincere desire to serve fellow humans, and a desire for self advancement. On the other hand there have been some troubles and cases where the electric heat did not perform as well as it should have; so we came together to find answers to real basic problems in the design of houses--problems which are seldom connected solely with electric heat.

A picture of the trends and history of insulation, a story of energy use, and an educated view of the future as presented by Mr. Sides is sufficient reason in itself to call the conference. In this time of rapid technological change we must be continually taught by specialists who know and understand the latest developments.

Some of the problems are:

How do actual heating loads compare with those calculated?

What methods of heat gain calculation give the nearest approximation to true gains?

Where and how should vapor barriers be installed?

What are good vapor barriers?

How does moisture condensation in insulation affect the U value?

How much insulation should be used?

How much ventilation is needed in the home?

Are high humidity conditions attending low infiltration desirable or harmful?

We have heard some very good answers to many of these problems. Actual heating loads may be lower than calculated as pointed out by Erickson and Boyd. They give the reasons, so future calculations can be more realistic. Brown substantiated the points of error by showing calculations to be reasonably accurate when solar gain and occupant and equipment input are not factors. Brown has shown the ASHRAE guide methods of heat loss and gain computation to be substantially correct. These methods should be used for sizing the heating and cooling equipment. Actual heat use will be less than such computations indicate because of the daily variations shown by Erickson.

Anderson taught us that moisture in insulation can cause rotting and corrosion if it continues over any long periods of time.

Brown, Boyd, and Sides challenged us to more accurately describe the insulation needed. It certainly seems naive to speak of the equivalent mineral wool thickness of insulation in the wall, floor and ceiling when so many other factors must be considered. Brown's suggestion to base our standard on B.t.u. heat loss or gain per square foot of floor area for a given time interval is more accurate, sophisticated, and usable for engineering calculation and commercial trade. It should be given serious study. Of course when speaking of insulation only and not the entire house as a unit of study, the "R" value is a good descriptive term to be used.

Vapor barriers can not be better than their installation, and are required only where it is necessary to drop the vapor gradient sharply. I would like to discuss this moisture movement problem a little more fully. It is the number one subject for inquiries of people writing to the Department of Agriculture for help with problems within the structure of the farm home. It is a subject which is often confused by engineers.

Mr. Scofield presented an excellent picture of the progress and limitations in the use of paint as permeable and non-permeable membranes. Our hats are off to the paint industries. Now we need only one more development--we need a paint with one-way permeability and with complete resistance to vapor flow in the opposite direction. Wouldn't this be ideal for painting both sides of the wall? But what if someone applied the paint up side down?

I am not satified with text-book answers on water vapor movement and vapor barriers. This appears to be a field for fruitful research. The water vapor present in a home (and even more important, that present in livestock shelters) has the latent heat of vaporization taken from within the building. We realize that we have to get rid of the water vapor or it will accumulate to such an extent that molds, bacteria and similar life which is not conducive to our life will gain an upper hand. So we sweep the vapor away by bringing in cold outside air and heating it. This is an illogical waste of heat. We want to condense the vapor, let it dribble outside as water, and use the latent heat of vaporization to warm the inside of our homes or other buildings. Quite a bit of research along this line has been done on livestock shelters, but the idea of heat exchangers has not been applied to homes.

When water condenses within a wall, it gives up latent heat of vaporization which reduces heat flow through the wall while the process of condensation is occuring. Should condensing window panes be constructed with thermostatic control to keep them at a dew point to control the inside humidity of the home? This may be a triple glass window with a double throw thermostat controlling a blower to deliver cold air from the outside across the outside of the inner pane when it calls for a cooler condensing surface, and a heater to prevent frosting if it gets too cold. Controlled condensation is not undesirable. The water from the condensate trough can be carried in a copper tube to the most convenient drain.

Odors would have to be controlled by internal filters instead of depending upon the process of dilution with fresh air. Having such a system of moisture and odor control, the only need for air exchange in the house is to furnish enough oxygen for life. That is an extremely small quantity of air.

I believe that the trend toward tightening the home has more possibilities than those which have been exploited up until this time. Today's home is far tighter than the houses of even 20 years ago, but we still are quite luxuriant in playing host to a lot of cold outside air. Erickson and Boyd show that 40% of the heating loss may go for infiltration and ventilation.

At the present time most of our houses are too dry for comfort in the winter time. While we run fans in baths and kitchens to exhaust too much water vapor we add humidifiers to our furnaces, radiators, or electric heaters to raise the humidity of the air. Admittedly, humidity control is not good either from the standpoint of distribution of water or amount of water in our homes of today. Research of the future should be able to find economical ways to giving uniform humidity conditions within the home by means of better circulation and mixing of the air, and control of the amount of moisture leaking from the house through the walls and through infiltration and ventilation.

If we can seal the windows tightly, and make effective air locks of the doors, a sizable proportion of the heat loss is eliminated.

Now the next greatest loss is through the windows. Triple glass windows are extensively used in Norway and Sweden. Erickson recommends them in Minnesota. Are there better and more effective ways of reducing heat loss through windows? Automobiles have motors to roll the windows up and down, so why is it beyond the realm of reason to have a set of window insulators which roll across the window openings at night? These can be translucent plastic foamed insulation so the northern windows will remain covered throughout the winter. The eastern windows will be uncovered from 8 a. m. to 10 a. m., the southern from 8 a. m. until 5 p. m., etc. The scheduled motor operation could be worked by cams on a time clock to gain full advantage of the solar intake through the windows; but, when the sun is not in the sky, to make the windows nearly as effective against heat loss as any other part of the wall.

The northern windows needed for outside view may be used as the dew point controllers having the internal air recirculation passing over them and then through reheaters to bring it back to house temperature before releasing.

In the summer heat gain situation the insulated closers can operate to reduce solar intake on the East and West. Brown showed us that a western window on a clear day takes in 90 B. t.u. per hour per square foot--65 when protected by inside drapes or venetian blinds, 35 for those shaded exteriorly.

The subject of vapor barriers is also a complex problem. It is simple to say, "Always install a vapor barrier on the warm side of any insulated wall". This just isn't a sound <u>general</u> structural rule. For example in bright leaf tobacco curing, the difference in vapor pressure between the inside and the outside of the barn may be 3 feet of water, but there is not a remote possibility of condensing water in the wall of a flue curing tobacco barn. The vapor moves through but there is no dew point in the wall. I do not believe there is any gain by putting a vapor barrier over radiant heating cable in the ceiling of a house. If the attic is ventilated, as emphasized by Anderson, it is difficult to theoretically visualize a condition where water vapor will condense in insulation above radiant heating cable.

If we are going to the expense of electrically heating a house, surely the house will be cooled in the summer. Then the outside becomes the warm side, and the old rule of thumb would indicate that a vapor barrier should be on both sides of the wall. This is a fine idea if vapor barriers are positive. Unfortunately almost all barriers let some moisture through, and if moisture enters a relatively tight bottle where it is difficult to escape our troubles are confounded. So the very worst thing that can be done to a house is to put a reasonably good vapor barrier on both sides of the wall.

In some cases the crawl space of a house may have a higher vapor pressure than the interior of the house even though the interior is warmer. Ground cover of 55 pound roll roofing is a good investment of any house with a crawl space, unless the house is located in an arid or semi-arid climate.

Here is a point that really confuses the engineers. They know that moisture rises from the ground beneath a house to pass upward through the house, that the crawl space is often damp, highly humid, and a place to release condensate causing "dry" rot and fungus growth on the floor joists. In the effort to prevent all of these ills it seems logical to place the vapor barrier on the under side of the flooring joists. Now on the other hand we know that the warm inner air of the modern home which is tightly constructed has a high vapor pressure which is almost certain to be higher than that of a ventilated crawl space on a cold winter day. Therefore, obviously to prevent condensation from forming in the insulation between the floor joists we had better put a good vapor barrier between the sub-floor and the finish floor. Now we find ourselves caught in the old "fish trap" of an imperfect barrier on both sides of the floor. When the water once gets in, it is difficult to get it out, and damage from deterioration is likely.

Each particular case must be considered on its own merit. If a crawl space does not get colder than about 50° F., there is very little likelihood that any vapor barrier is needed on either side of the insulation. But here again, this is a general statement which does not consider the facts of the individual case. If the crawl space has no ground cover, if the soil is damp beneath the house, and if the inside of the house is air conditioned, a barrier beneath the floor joists would be correct.

Another much debated item on which there appears a need for clarification is that of wall ventilation. If everything is under perfect control so we can control the temperature of some given surface within a wall, the temptation to omit vapor barriers on the inside, and to install a controlled condensation plate within the wall is great. Condensation on a non-corrosive surface within a wall would eliminate problems of blistering paint, swelling wood, rot, and insulation breakdown. The difficulty in applying this principle is in the failure to control temperatures and moisture. We can not with the present techniques insure that the dew point temperature will always occur on the condensation plate. It may still occur within the insulation.

Attempts to form flue like ventilation chimneys near the outside portion of a wall have not always resulted in proper ventilation. Venting individual siding boards or shingles has been recommended, but evidence has not been compiled to show whether this recommendation actually has merit. Without a doubt there are occasions when it is very important to have free passage of water vapor through the exterior of the wall, and a lot of our moisture problems are aggravated because the permeability of the outer wall surface is too restricted. On the other hand, it is difficult to obtain a balance between permeability to water vapor and moisture proofing from blowing rain.

The picture is not as gloomy as I have been painting it. The problems are new. Before we had tight homes, and better control of heat and moisture, the vapor barriers and insulation were not of primary importance. Now they are. Progress in finding excellent techniques for meeting these problems is tremendous. New materials such as foamed-in-place urethane as discussed by R. L. Checkel, new methods of applying heat, new methods of ventilating, all combine to increase the comfort of our homes far beyond the dreams of the 19th century. More than a picture of gloom, the picture painted is one of hope and confidence that research will continue its rapid pace to discover continually better methods of environmental control in the home.

This conference testifies to the accuracy of this prediction.

ROSTER

of

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